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STABILITY OF STREAM COMMUNITIES EXPOSED TO UNDERGROUND NUCLEAR

TESTS ON AMCHITKA, ALEUTIAN ISLANDS, ALASKA

by

Richard Ames Valdez

A dissertation submitted in partial fulfillment
of the requirements for the degree

of

DOCTOR OF PHILOSOPHY

in

Wildlife Science

Approved:

Major Professor

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Dean of Graduate Studies

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Richard Ames Valdez

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ABSTRACT

Stability of Stream Communities Exposed to Underground Nuclear

Tests on Amchitka, Aleutian Islands, Alaska

by

Richard Ames Valdez, Doctor of Philosophy

Utah State University, 1975

Major Professor: Dr. William T. Helm

Department: Wildlife Science

A major bioenvironmental effect of The United States Atomic Energy Commission's Underground Nuclear Testing Program on Amchitka Island, Alaska was the decimation of stream communities by drilling muds from the device emplacement holes. These muds reached two of these streams 4 months and 2 years before the Milrow and Cannikin tests, respectively. Recolonization of fishes and macroinvertebrates in these small streams (Clevenger and White Alice Creeks) began 1 month after spill abatement.

Complete recovery of Dolly Varden in Clevenger Creek occurred less than 5 years after the spill. Of the other native fishes, pink salmon spawned $1\frac{1}{2}$ years after the spill and threespine stickleback, which were formerly rare in the stream, remained absent after 5 years. Although the midge Chironomus riparius recovered completely in $2\frac{1}{2}$ years, populations of three of the nine sympatric macroinvertebrates were still below the pre-spill densities after 5 years. Annual production of juvenile Dolly Varden in Clevenger Creek 3 and 4 years after the spill (42.45 and 43.58 kg ha⁻¹, dry weight) surpassed the pre-spill estimate (40.21 kg ha⁻¹) because of the predominance of new year classes in the recovering population, and not because of increased growth rates. Annual produc-

tion of the recovering midges in Clevenger Creek 3 years after the spill was about $1\frac{1}{2}$ times the pre-spill estimate (8.12 and 12.01 gm m⁻², dry weight), because of high densities from reduced competition by sympatric macroinvertebrates and predation by Dolly Varden. Rapid expulsion of the pollutant by high runoffs and immigration of individuals from unaffected areas of the stream sped the initial recolonization. The increased turbidity and some bank sloughing caused by the Milrow event did not hinder this recovery.

The spill that decimated the communities of White Alice Creek, persisted for $1\frac{1}{2}$ years and slowed the recovery of fishes and macroinvertebrates in that stream. Physical damage and alteration of stream habitat by the Cannikin device further inhibited recolonization.

Macroinvertebrate species diversity of unperturbed Amchitka streams was low when compared to that of continental streams. The response of this index to seasonal variations in density invalidated its use as a sensitivity index to perturbations in these simply-structured island communities. The stability of these low diversity communities was not thoroughly evaluated, since their resistance was not thoroughly tested; the mud spills seemed toxic enough to have decimated most stream populations. However, resilience, or the reoperative process, appeared high as indicated by rapid recolonization of native species after abatement.

INTRODUCTION

Darwin's visit to the Galapagos Islands in the 1830's revealed not only a uniqueness in evolutionary development among insular plants and animals, but also a contrast in the diversity of species between islands and continents. It is well established that islands support fewer species per unit area than continents, at similar latitudes. This diversity of species, among many terrestrial plants and animals, is lower yet in the smaller, more remote islands (Preston, 1962; MacArthur and Wilson, 1967). The concept of latitudinal diversity is equally recognized; terrestrial and aquatic communities in the tropics support a greater diversity of species than those in the temperate and arctic regions (Pianka, 1966; Lowe-McConnell, 1969).

The phenomena of suppressed insular and latitudinal species diversity can both be observed on Amchitka Island, in the subarctic Aleutian Archipelago. This island is nearly 1,000 km from both the Alaska and Kamchatka Peninsulas of the North American and Asian continents, respectively. Amchitka supports less than 200 species of vascular plants (Shacklette et al., 1969), 27 species of nesting birds (Williamson, Emison, and White, 1971), three species of marine mammals, and no native terrestrial mammals (McCann, 1962). Its fauna and flora are much like that of the evolutionary immature tundra biome of the Alaskan mainland, but the variety of terrestrial species is lacking. The freshwater communities of Amchitka similarly support a low diversity of aquatic species (Neuhold, Helm, and Valdez, 1971), when compared to

those of small, inland or coastal streams of the mainland (Chapman and Demory, 1963; Hynes, 1970); most Amchitka streams support one or two species of fishes and eight to ten species of macroinvertebrates.

The response of communities to unnatural perturbations is strongly dependent upon the variety or diversity of species that inhabit them (Margalef, 1958, 1968). Amchitka provides an excellent opportunity to examine community structure and its functions as a means of evaluating the response of low diversity communities to perturbations, since it abounds in small ponds and streams and has been the site of moderate human activities.

The communities of two maritime streams on Amchitka were examined from 1968 to 1973 to evaluate the impact of two nuclear weapons tests conducted by the United States Atomic Energy Commission (AEC). The purpose of these tests was to proof-test the Spartan Warhead for use in the Safeguard Antiballistic Missile (ABM) System. Both the Milrow and Cannikin devices were denoted underground to reduce the possibility of immediate radionuclide contamination. Significant biological effects occurred before either detonation, when drilling muds from the device emplacement holes spilled into about 70 percent of the total area of the small stream adjacent to each test site. The emphasis of this study was thus redirected from the effect of the weapons tests to that of the drilling mud spills, since the coating effect of these muds, in combination with their hazardous chemicals, decimated the benthic invertebrates and fishes in the receiving waters. The upper reaches of both streams, as well as some tributaries, remained unaffected. Other streams and ponds on Amchitka were similarly affected by other drilling activities, but only two streams are considered in this study. Similar

problems, from the disposal of mud tailings, have been reported on the Arctic Slope and Beaufort Sea from oil and gas developments (Brooks et al., 1971).

Although the impact of man's disturbances on waterways is well documented (Warren, 1971), studies on perturbed aquatic communities of low diversity are few. The theoretical view that higher species diversity brings about greater community stability in simple systems has been tested only in laboratory microcosms of bacteria and protozoa (Hairston et al., 1968). In these experiments, additional species of paramecia did not increase stability. Watt (1965) concluded from studies of forest insect pests that species with broad diets are more unstable than those with restricted diets. These studies indicate that the hypothesis relating species diversity to community stability is in need of further scrutiny.

The impact of mud tailings on community stability, and the resultant structure of those communities, were examined. The objectives of this study were to 1) gather baseline information of unperturbed stream communities by determining densities, production, and birth, growth and death rates of fish and macroinvertebrate populations, 2) examine the same communities, in the same manner, after the perturbation, and 3) integrate the findings of objectives 1 and 2 into an evaluation of the tolerance and reoperative process of these stream communities. My hypothesis was that, although the resistance of these insular aquatic communities to unnatural perturbations is low, their resilience or ability to return to their predisturbed state, is high. This study encompasses an area of community stability that has not been thoroughly

explored; the response of low diversity aquatic communities to unnatural perturbations.

In the low diversity communities of Amchitka streams, each trophic level is dominated by a single species largely responsible for energy transfer. An increase or reduction in abundance of this key species is likely to result in catastrophic effects to other communal species, altering the entire structure of the community. However, once the perturbation is removed, the energy paths of these insular communities are so few and direct that reinstatement of the original structure is expected with greater rapidity than in communities with more species and a more complex food web.

TERMINOLOGY

Species Diversity

Species diversity considers the number of species present in a community (variety) as well as the relative abundance of each (evenness). Communities are composed of a relatively small percentage of abundant species and a large percentage of rare species. Although the few common species contribute to the bulk of energy flow through the system, it is all of the species that account for the diversity of the community. Simply stated, maximum species diversity exists if each individual belongs to a different species, and minimum diversity if all belong to the same species. Higher diversity in a community means longer food chains and more possibilities for symbiosis (mutualism, parasitism, commensalism). This leads to greater possibilities of negative feedback control to reduce oscillations in populations and hence, increased community stability (Margalef, 1968; Odum, 1971).

Some investigators feel that species diversity indices are one of the best ways to detect and evaluate pollution, particularly in lotic environments, since long term effects of chemical or physical disturbances are eventually reflected in the biota. Chemical water analyses are only instantaneous measures of pollution, and unless constant monitoring is conducted, pollutants may go undetected and their impact hardly observed (Wilhm and Dorris, 1968; Warren, 1971). Most studies that employ species diversity as a way to detect and evaluate aquatic pollution concern themselves with either macroinvertebrates (Gaufin and

Tarzwel, 1956; Reish and Winter, 1964; Wilhm and Dorris, 1966; Reger, 1973) or fishes (Bergerson, 1972; Sigler et al., 1972).

Community Stability

Stability is an equilibrium point of ecology that is of increasing concern in natural communities, in light of man's attempt to manipulate these systems for his benefit. Knowledge of the behavior of a community to outside stresses has become a very significant aspect of modular and simulation ecosystem ecology (Regier and Henderson, 1973). Thermodynamically, stability is the ability of a system to maintain or return to its ground state after an external perturbation. The degree of stability is characterized by the amplitude of the deflection from the ground state, the rapidity of response to the perturbation, and the rate at which any deflection is damped (von Foerster, 1957). Thus, stability in biological communities is the constancy of systems brought about by self-regulating mechanisms. All communities are subject to natural perturbations, to which they have adjusted. It is the large changes in density and species composition, brought about by unpredictable or unnatural external forces, that disrupt community stability. The resultant instability may vary in the different trophic levels (Watt, 1965; Hurd et al., 1971).

In this study, stability is divided into resistance and resilience. The tolerance of communities to unnatural perturbations, as measured by decrease - or decimation - of the various populations, is a qualitative expression of resistance. Resilience refers to the rapidity with which

a community returns to its pre-disturbed state. It is largely a function of:

- 1) the extent of the perturbation,
- 2) the degree to which the native populations are affected,
- 3) the degree to which the pollutant is expelled or the perturbation dissipated, and
- 4) the availability of brood stocks or sources of recruitment.

DESCRIPTION OF AMCHITKA

Location and Terrain

Amchitka is the largest island in the Rat Group of the Aleutians. It is one of the southernmost landmarks of the archipelago, located at about 179°E longitude and $51^{\circ} 30'\text{N}$ latitude (Figure 1). Amchitka is about 68 km long and 7 km at its widest point. The terrain of the entire island is interrupted by numerous small streams and rivulets that drain perpendicular to its longest axis, either into the Bering Sea or into the Pacific Ocean. These drainages are usually only 3 to 4 km long and originate in either small ponds on plateaus, or in springs on marshy areas.

The southeastern portion of the island is flat low tundra with a maximum elevation of about 100 m. It is dotted with an abundance of small shallow ponds and potholes, none exceeding 30 ha in surface area (McCann, 1962; Palmisano, 1971). Northwestern Amchitka is hilly with fewer ponds and a maximum elevation of about 350 km.

Amchitka is volcanic in origin, as are most of its neighboring islands. It is covered with a variety of low-growing vegetation types that form a heath on a thin soil layer, but the island is completely treeless. The moderate maritime winter temperatures prevent the formation of permafrost in the soil. A description of the pedology of Amchitka was presented by Everett (1968), while Shacklette et al. (1969) provided descriptions of the terrestrial and aquatic vegetation.

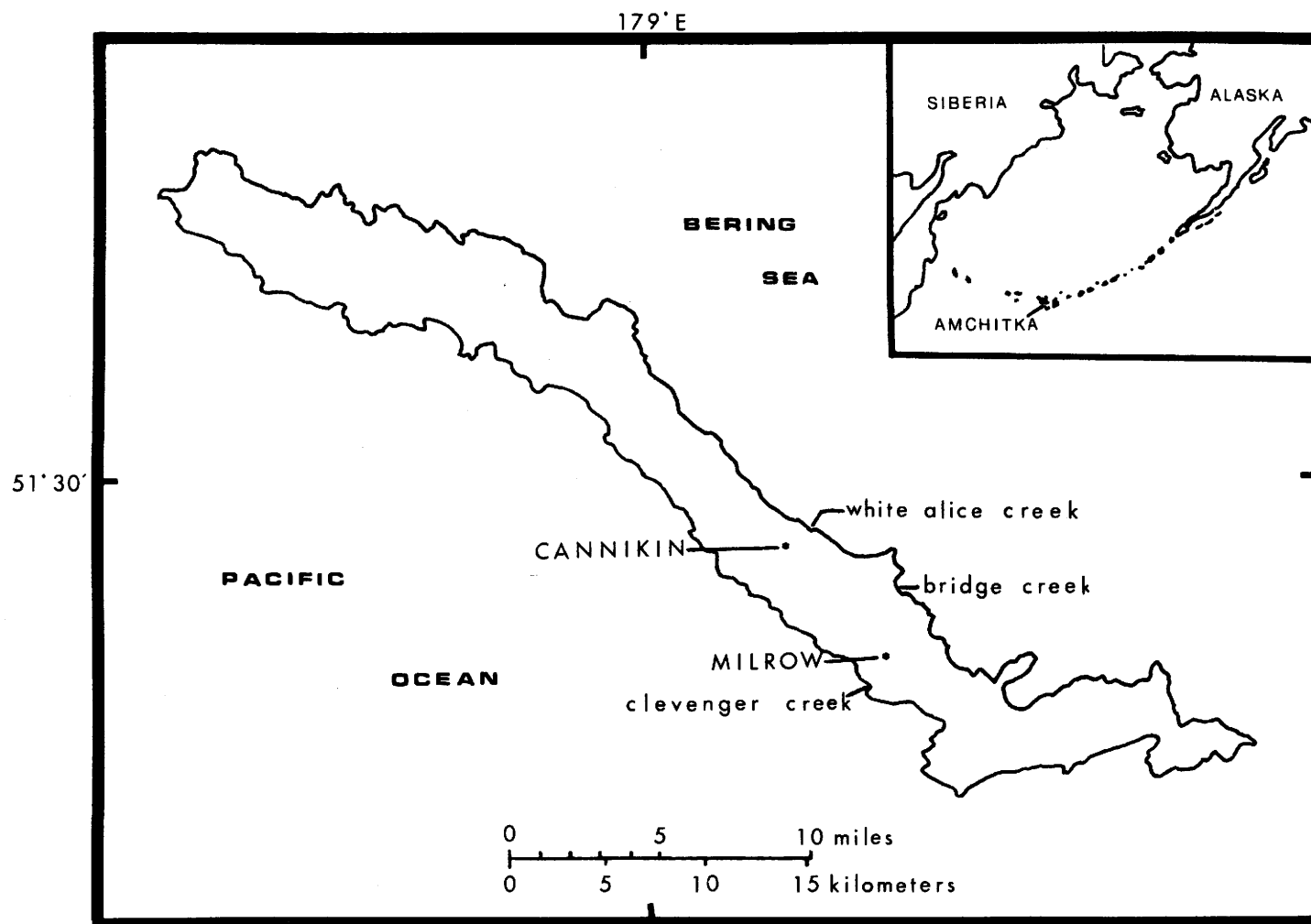


Figure 1. Location of test sites and study streams on Amchitka.

Climate

Extremes in air temperature on Amchitka since 1943 ranged from -9.4 C to 18.3 C with an annual mean of 4.5 C. Mean annual precipitation for the same period varied from 76 to 89 cm including an average annual snowfall of 178 cm (Anonymous, 1969).

Most precipitation on Amchitka in 1969 and 1970 occurred from July to January (Figure 2). Stream flow was highest and most responsive to precipitation levels from August to February, as is demonstrated for Clevenger and White Alice Creeks. In May, June and especially July, stream discharge responded poorly to precipitation. Fenske (1972) suggested that Amchitka is at flow capacity all year except during May and June, when some infiltration occurs before runoff begins. As a result, a delay of about 1 month was observed in late summer between the increase in precipitation and the corresponding increase in stream discharge. This "sponge effect" significantly affected stream levels in late summer and influenced the dynamics of the stream communities, particularly the movement of fishes.

Freshwater Fauna

Macroinvertebrates

The more commonly occurring and biologically significant aquatic macroinvertebrates of Amchitka are representatives of the phyla Nematoda, Annelida, Mollusca and Arthropoda. Palmisano (1971) and Valdez (1971) inventoried these and other less common forms in lists of

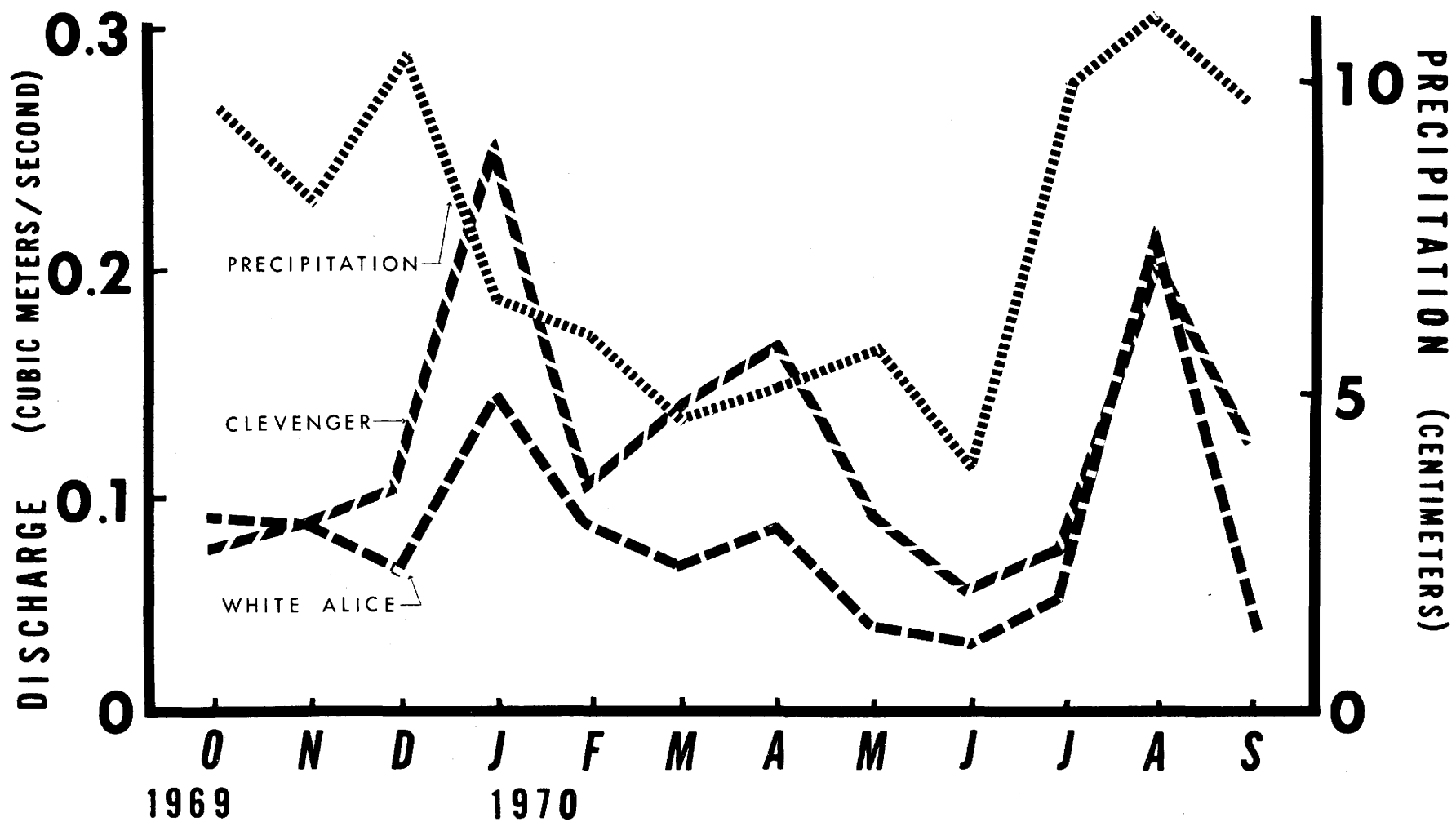


Figure 2. Mean monthly percipitation and discharge of Clevenger and White Alice Creeks for October 1969 through September 1970. The data are a courtesy of the United States Geological Survey (USGS).

food items consumed by Dolly Varden, Salvelinus malma, and threespine stickleback, Gasterosteus aculeatus, on Amchitka.

Nematodes and annelids were common in soft mud ponds and at the mouths of streams, near the high marine intertidal zone. Nematodes abounded in decaying marine algae that was tossed or washed into the stream by oceanic storms, and oligochaetes were frequently encountered in the gravel, sand and mud of stream mouths.

The molluscan forms, Pelecypoda and Gastropoda, occurred in all of the larger mud bottom ponds sampled, but were abundant in only about one-third of these. The pelecypods are represented by fingernail clams (Pisidium sp.) and the larger Anodonta beringiana. A small, short snail of the family Lymnaeidae (Lymnaea abrusa) was commonly found with the fingernail clams in these ponds.

Two classes of arthropods, Insecta and Crustacea, dominated the numbers of macroinvertebrates in Amchitka's freshwaters. Few crustaceans were found in streams, except for amphipods (Hyalolella sp.), which frequented the slow-flowing waters. An abundance of crustaceans including amphipods (Corophium spinicorne), isopods (Gnoringosphaeroma lutea) and some mysids (Acanthomysis awatchensis) was found in most large ponds.

Only a few species of aquatic insects inhabited the island's freshwaters. The most striking feature of this system was the complete absence of mosquitoes (Culicidae). The orders Ephemeroptera (mayflies), Trichoptera (caddisflies), Diptera (blackflies and midges), Hemiptera (water boatmen) and Coleoptera (diving beetles) were common. Their nymphal, larval, and pupal stages were benthic or demersal in the streams and ponds.

Life history of Chironomus riparius. Since the response of the midge Chironomus riparius to drilling muds is emphasized in this study, a review of its life history is warranted.

Adults emerge and oviposit in late summer, usually in September. Eggs incubate throughout the winter months and, by the following spring, the larvae are macroscopic. Individuals appeared in samples in June and July, at which time they were large enough to sort manually, with the aid of forceps. Growth throughout the summer is rapid until pupation and subsequent emergence. Since a single cohort expires in 1 year, the life cycle of this species is designated as univoltine.

Fishes

Amchitka supports six species of freshwater fishes including four anadromous salmonids, one stickleback, and one cottid. Dolly Varden and threespine stickleback were abundant throughout the island (McCann, 1962; Neuhold, Helm, and Valdez, 1971). The former predominated in streams and larger ponds, while the latter was found primarily in smaller ponds. Pink salmon, Oncorhynchus gorbuscha, and silver salmon, O. kisutch, spawned in as many as 21 and 5 streams, respectively (Neuhold et al., 1971). Sockeye salmon, O. nerka, and coastrange sculpin, Cottus aleuticus, were restricted to one and three drainages, respectively.

The predominance of the Dolly Varden on Amchitka was realized when it was encountered in all of 34 perennial streams visited in a salmon survey (Neuhold, Helm, and Valdez, 1970). In many, Dolly Varden were accompanied by a few stickleback, salmon, or both, but in most it was the only fish species found. An anadromous form was

encountered in those streams accessible to sea-run fish, while those streams with waterfalls near their mouth supported only a dwarfed landlocked form. The Dolly Varden was the most important top carnivore in the stream communities and provided an excellent index to the influence of man's perturbations on the higher trophic levels of a seemingly simple system. Neuhold (1971) demonstrated the dependence of the Dolly Varden on midges in Amchitka streams. It is for this fish's abundance, ubiquity and position in the food web that its response to perturbations in stream communities is emphasized and its life history now reviewed.

Life history of *Salvelinus malma*. The life history of the Dolly Varden on Amchitka is similar to that described in southeastern Alaska by Armstrong (1970). Dolly Varden hatch on Amchitka, usually under snow and ice-laden streams, in February and March. By June, after having absorbed their yolk sac, the young leave their gravel redds and seek the shelter of nearby stream vegetation, where they feed actively on immature insects and small crustaceans. At about 2 years of age, the young char begin to stray from the dense vegetation to the more open pools, using nearby undercut banks as shelter. In the anadromous form, those young fish closest to the sea often stray into the intertidal zone during high tide and then return to the stream before low tide. Similar movement was reported by Armstrong (1974) in southeastern Alaska. On Amchitka, it is interpreted as a search for food in the bountiful intertidal zone.

Anadromous char on Amchitka smoltify as age groups III and IV, or at about 100 and 130 mm standard length (SL), respectively. Parr

marks begin to fade, and seaward descent occurs in June and July, continuing intermittently throughout the summer.

The abundance of food at sea brings about accelerated growth and enhanced robustness in the adults. These feed actively on intertidal invertebrates and small littoral fishes, usually nocturnally, near stream mouths and during high tide. Dolly Varden of Amchitka, in 1970, spent an average of 73 days at sea, in which time average weight gained per fish was 182 gm and average increase in length was 27 mm.

Heavy rains in August and September swell the small island streams and apparently make more favorable an ascent by the anadromous char, which are often accompanied by some adult pink salmon. Large movements of these fishes occurred only during these freshets. Returning char have bright silvery sides with light green backs and are in excellent condition. The color of each fish begins to darken after about 1 week in the stream, and by spawning time, in October and November, the males turn a bright green atop with blood red sides and belly. This, and the development of a kype on the mandible, distinguishes the male from the more drab, greenish-colored female. Degeneration of robustness occurred in these sea-run fish soon after spawning, since they appear to fast while in the stream, about 286 days. Weight loss during this 8 to 9 month fast was very marked, an average of 158 gm, or 30 percent of the body weight ($n = 26$ fish).

Mortality was high among spawning Dolly Varden, but unlike the Pacific salmon, between 50 and 60 percent of these adults survived to descend seaward in June with the smolts. Char on Amchitka were found ascending to spawn for a third time in a 3 year period.

In contrast to the anadromous char of Clevenger Creek, the landlocked form of White Alice Creek exhibited little movement either to spawn or feed. Both forms mature at 3 or 4 years of age, but the landlocked form relies on the scant food supply of the streams. Thus, their eventually size is much less than that of the anadromous char.

THE TWO STUDY STREAMS

Physical and Biological Aspects

Both streams considered in this study flowed adjacent to test sites (Figure 1). Clevenger Creek drained a small pond next to the Milrow drilling pad, while the northwest branch of White Alice Creek flowed adjacent to the Cannikin drilling pad. Both of these Amchitka streams are considered "lowland streams" (Neuhold, 1971).

Clevenger Creek drained a larger watershed than White Alice Creek (Table 7, see appendix) and carried more water, although flow patterns for the two were very similar (Figure 2). Both streams meandered similarly through gentle tundra-covered valleys, but White Alice Creek had a slightly steeper gradient and a higher velocity flow. The substrate of both streams was predominantly mud, with a far greater proportion of pools than riffles (Table 7, see appendix).

Clevenger Creek

The nature of the Clevenger Creek outlet permitted an inhabitation by anadromous fishes. Before test activities, Dolly Varden were abundant, but silver and pink salmon were present only in low numbers. A few threespine stickleback inhabited the low velocity pools near the mouth.

The ten forms of benthic macroinvertebrates in Clevenger Creek were dominated in numbers by chironomids, in bottom muds and dense growths of Fontinalis neomexicanus. Some ephemeropterans (Pseudocloeon sp.) and trichopterans (Limnophilidae) were found in the rock substrate (Table 8, see appendix).

White Alice Creek

White Alice Creek had an outlet that cascaded over a sea cliff about 10 m high and did not permit access to anadromous fishes. Thus, the population of Dolly Varden in this stream was a dwarfed landlocked form. A few threespine stickleback inhabited the small ponds that drained into White Alice Creek, but these were rare in the stream proper.

The number of macroinvertebrate species in White Alice Creek, like the number of fish species, was low (Table 8, see appendix). Chironomids, trichopterans (Limnephilidae) and oligochaetes were the most numerous forms of this benthic fauna.

Four species of aquatic macrophytes were abundant in White Alice Creek. Fontinalis neomexicanus and Mnium sp. flourished to provide an important habitat for fishes and invertebrates.

AEC Activities and Their Effects

Major test-related activities for both the Milrow and Cannikin events were similar in chronology and can be separated into four stages:

1. road construction to the site,
2. drill pad construction,
3. emplacement hole excavation (drilling) and retention of mud tailings in surface earthen pits or sumps, and
4. detonation.

Road and pad construction

Road and drill pad construction caused considerable siltation in the streams draining both test sites. The freshets in these short

drainages provided rapid flushing action, which removed much of this silt. Nevertheless, chronic siltation was observed, that could result in suffocation of vegetation, benthic invertebrates, and fish eggs and fry in redd areas (Neuhold et al., 1971).

Drilling

During the drilling stage of each event, material extracted from the emplacement holes was pumped to the surface and held in large earthen pits or sumps; excavations in the tundra with earthen dikes as walls. These sumps were about 15 m by 25 m and 2 m in depth. The emplacement holes for the Milrow and Cannikin devices were about 1,200 m and 1,800 m deep and about 1.0 m and 1.3 m in diameter, respectively. This gives some idea of the volume of material extracted from each emplacement hole and held in the sumps.

The approximate composition of a specially prepared solvent used for drilling was 91 to 93 percent water and 6 to 8 percent diesel fuel oil. Additives such as bentonite, cement, sodium bicarbonate, shredded paper and Q-BROXIN¹ (ferrochrome lignosulfate, and calcium lignosulfate used as a thinner and filtration control agent) were used to maintain a desired viscosity and consistency. The pH of this material, before use as a drilling suspension, was between 10.0 and 12.0. Its hazards in mixture with suspended rock bits and mud, as well as heated water, when introduced into streams, are obvious. It was the escape of this muddy fluid into Clevenger and White Alice Creeks that, in both cases, initiated effects upon the stream communities.

¹Q-BROXIN is a Registered Trademark of Georgia Pacific Corp.

Clevenger Creek. The first spill of drilling mud from the Milrow test site was small. This probably occurred about January 1968, after the failure of an earthen sump wall. No additional spills occurred that year. The stream was subjected to the usual series of freshets, particularly in late summer and fall, (Figure 2) that sped the flushing of the mud and oil residue. Since the spill did not persist, little evidence of oil remained by late summer 1968.

A second spill occurred in mid-May 1969, reaching Clevenger Creek at the same location as the first (Figure 3). However, this spill persisted from mid-May to mid-June, during which time about 30,000 barrels of drilling mud entered the stream. Mud and oil residue was evident in aquatic vegetation, sand, gravel and mud throughout the summer of 1969, but this was flushed from the stream by freshets in August and September (Figure 2). These freshets, enhanced expulsion of the otherwise persistent fuel oil (Blumer and Sass, 1972) in both Clevenger and White Alice Creeks.

The Milrow device, detonated October 2, 1969 at the upper end of Clevenger Creek, caused considerable bank sloughing and resuspension of much of the oil residue and sedimented drilling mud. The water in this stream had a dark brown color for 2 days after the detonation, but no further disturbance was detected after the Milrow event.

White Alice Creek. Frequent contamination of White Alice Creek from the Cannikin site occurred from the summer of 1968 until just prior to the Cannikin event, November 6, 1971. Evidence of the four largest spills was found in June 1970, originating from either drain pipes, trenches or breaks in the sump walls. Both the northwestern and

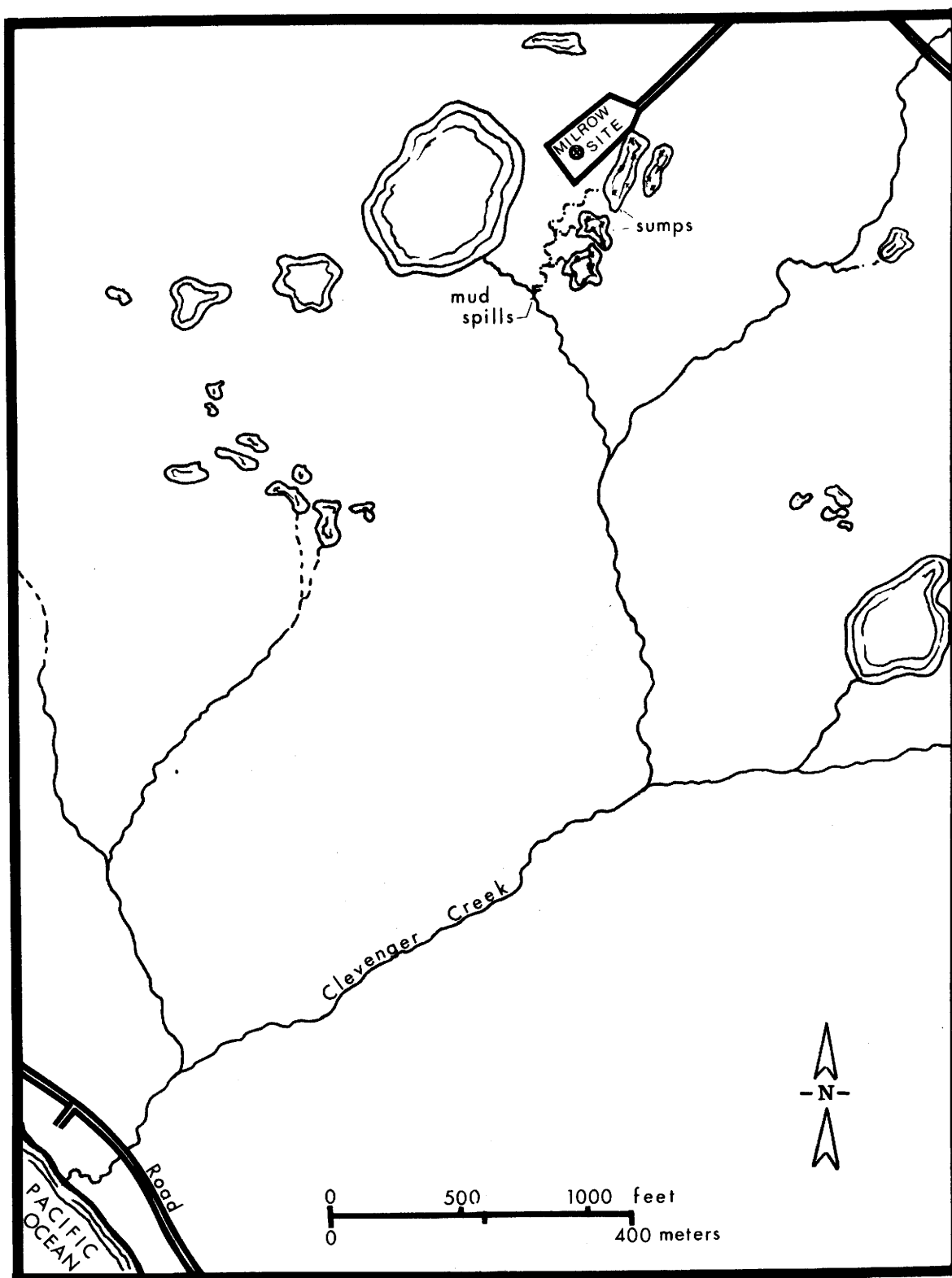


Figure 3. Location of the mud spill from the Milrow test site into Clevenger Creek.

southeastern branches of the stream received frequent spills (Figure 4a). The stream bed was covered with caked and peeling mud and silt, while oil was very evident by its odor and appearance in mud and stream vegetation. A heavy precipitate was probably caused by high concentration of sodium bicarbonate and divalent metallic cations (calcium and magnesium) in the original drilling solvent. Much of the benthic fauna suffocated from this precipitate and the oil.

The flow of material from one sump into the northwestern branch of the stream was continuous from June 1970 to September 1971. During the summer of 1970, the fluid was rich with mud and suspended particles, and flowed at a rate of $0.0056 \text{ m}^3 \text{ sec}^{-1}$ ($0.20 \text{ ft}^3 \text{ sec}^{-1}$). According to Dr. Don D. Gonzalez², mean flow of the main branch of White Alice Creek was $0.054 \text{ m}^3 \text{ sec}^{-1}$ ($1.90 \text{ ft}^3 \text{ sec}^{-1}$) and flow in the receiving northwestern branch was about $0.027 \text{ m}^3 \text{ sec}^{-1}$ ($0.96 \text{ ft}^3 \text{ sec}^{-1}$). This resulted in a concentration of drilling mud of about 21 percent. Bioassays indicate that concentrations of 8 and 15 percent at 8 C water temperature are lethal to Dolly Varden and threespine stickleback, respectively (Neuhold, Helm, and Valdez, 1972). All fish downstream from the spill point were likely killed by the toxic liquid. Evidence indicates that spills of similar or larger magnitude also occurred in the southeastern branch. An estimated 40,000 barrels of drilling mud was released into the stream, all total.

By the summer of 1971, the spill was composed primarily of the supernatant liquid in a sump, which appeared quite clear and was relatively free of pollutants. However, this sump received a steady

²Personal communication with Dr. Don D. Gonzalez, U.S. Geological Survey, Denver Federal Center, Denver, Colorado, August, 1972.

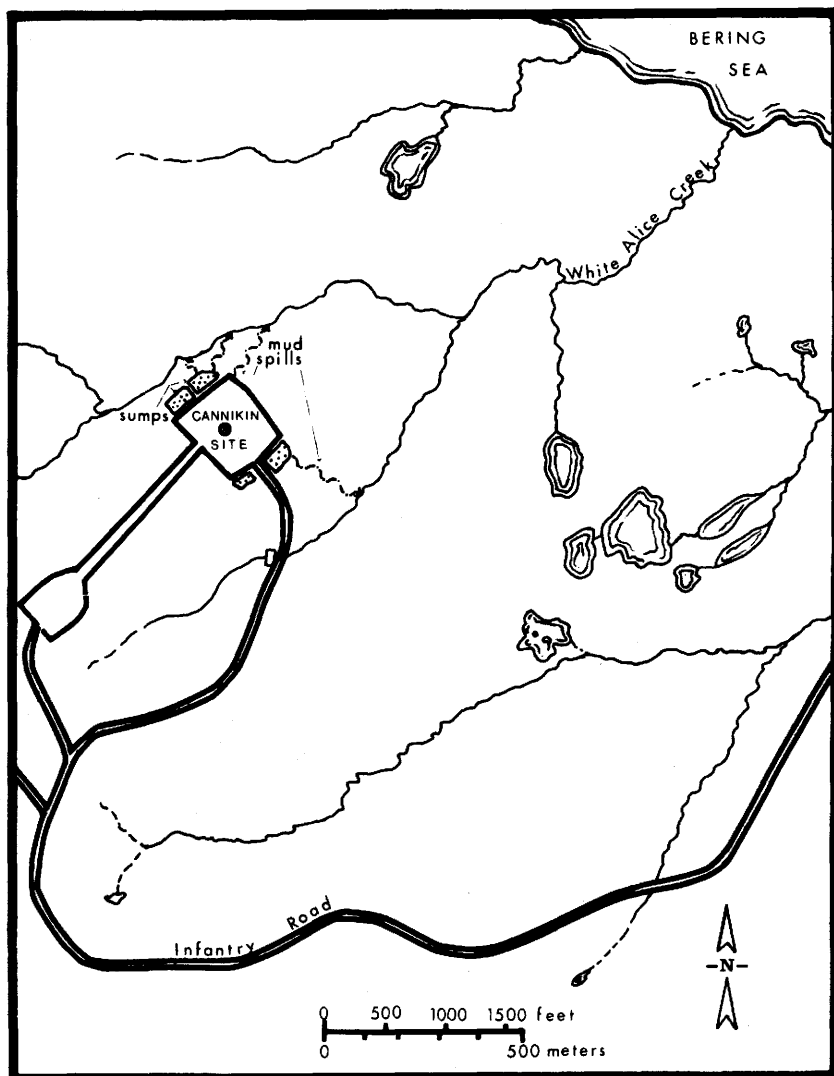


Figure 4a. Location of mud spills from the Cannikin test site into White Alice Creek before the nuclear test.

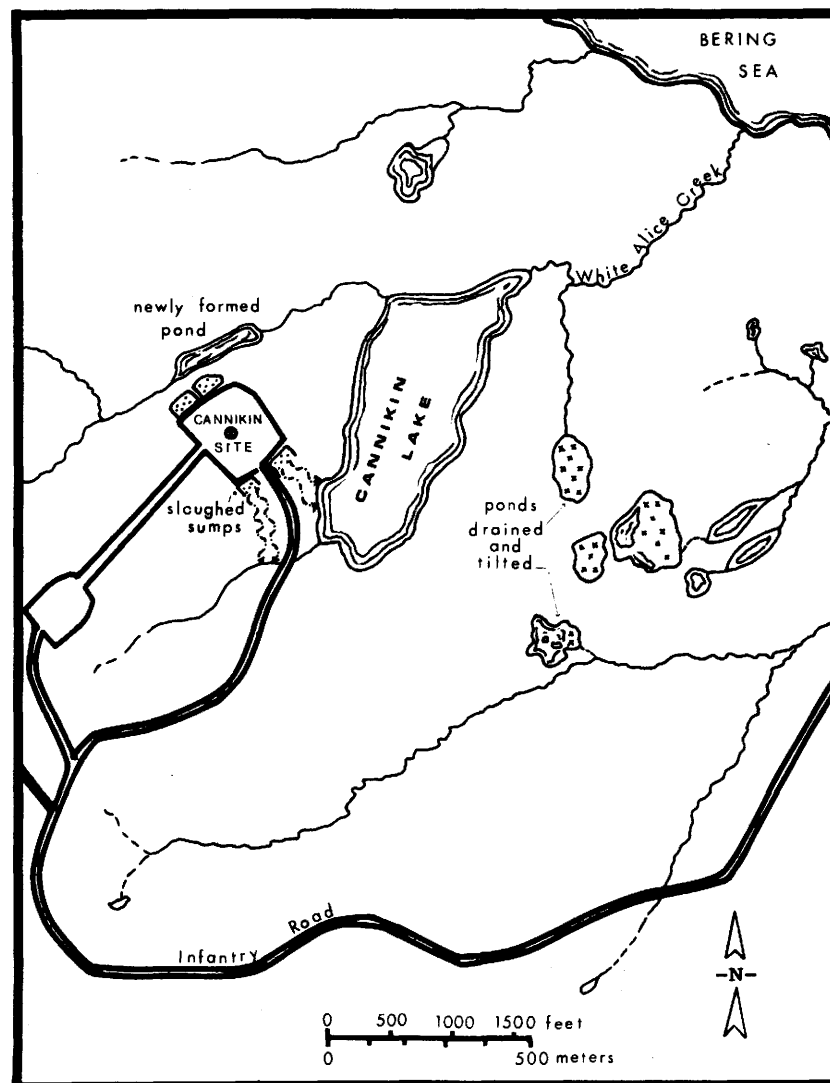


Figure 4b. The White Alice Watershed after subsidence of the Cannikin crater.

stream of warm water (32 C) from the Cannikin emplacement hole resulting in a surface temperature of about 15 C. By the time this water reached the stream, about 75 m below the sump, it had cooled to about 13 C. White Alice Creek during June, July and August 1971 averaged 7 C. At the point where the stream and the spill mixed, the water temperature became 9 C and it was 100 m downstream before it finally cooled back to 7 C.

Thus, flows of drilling mud into White Alice Creek were not only chronic and at concentrations lethal to the fish and invertebrate populations, but these also presented a local thermal pollution problem.

Detonation

The effects of the Milrow and Cannikin detonations were thoroughly documented by Merritt (1970, 1973). Live pen experiments were conducted in freshwaters during both events, and pressure wave measurements were recorded during Cannikin. The effect of pressure generation on freshwater fishes was restricted to the physoclistous species in ponds; ruptured air bladders were common in threespine stickleback, but did not occur in the salmonids. Some ponds were partially or completely drained by the blasts, stranding Dolly Varden and threespine stickleback.

In some streams, only sloughing of banks occurred, but in others, entire sections were rechanneled. In the case of White Alice Creek, numerous fractures in the drainage and eventual cratering of the old stream bed formed a basin for the largest body of water on the island, Cannikin Lake (Figure 4b).

METHODS

The effects of mud tailings on communities of Amchitka streams were evaluated by enumerating species of macroinvertebrates and fishes and their abundance, before and after the spills. Estimates of birth, growth and death rates, as well as production of the key species in the communities were also determined monthly, except where sampling was hindered by the winter weather and access to Amchitka.

Each stream examined was divided into intervals of 30 m, stream distance, with serially labeled wooden stakes driven into the stream bank. Clevenger Creek, with an outlet accessible to anadromous fishes, was measured from the mouth at the high intertidal mark, upstream 1,886 m to two small ponds in the upper watershed. The total area of the stream was about 0.20 ha. The study area in White Alice Creek was 1,624 m long and total stream area was about 0.22 ha.

A reconnaissance of fishes and macroinvertebrates indicated that the densities of these varied according to three longitudinal strata; the upper, middle, and lower reaches of stream. This natural division was a function of the changes in gradient, stream width and bottom type that occurred most abruptly between the plateau and drainage basin, and the drainage basin and flood plain of the stream. The lower strata, composed of large pools near the intertidal zone, supported the highest densities of organisms. The upper strata had the lowest density and the middle strata, intermediate density. Both streams were divided into three approximately equidistant strata, so that sampling could be done within each to yield reliable estimates of stream fauna representative of the bottom type and habitat of that stratum.

Sampling

Macroinvertebrates

Benthic macroinvertebrates were sampled in gravel and shallow stream areas with a Surber sampler (929 cm^2), and in deep slow-flowing water, on soft mud bottoms, with an Ekman dredge (232 cm^2).

Fishes

Dolly Varden were captured in the streams by electrofishing, and their movement was monitored by two-way fish weirs.

All of the sampling effort was directed toward estimating the density and biomass of this char. Fish were captured to mark (by clipped fins and tags) and introduce recognizable individuals into the population for estimates by mark and recapture techniques. In addition, char were captured, held and released, as part of a removal program also used to estimate their density.

Electrofishing. A one horsepower, two cycle gasoline engine with a 110 volt alternating current alternator³ was used to stun fish for capture with long-handled landing nets. The engine and alternator were mounted on a backpack frame for ease of transport into remote areas and for carrying during operation. Two netters, one carrying the shocker, and each with an electrode, made all fish collections. Care was taken not to carry too many stunned fish in either landing net, so these were emptied periodically into water-filled pans along the streambank. Usually a 30 m section of stream was electrofished before stopping to weigh, measure, mark and release the fish.

³Fish shocker was assembled by Coffelt Electronics, 4090 W. Radcliffe Ave., Denver, Colorado 80236.

Weirs. A fish weir similar to that described by Wolf (1950) was built in Clevenger Creek about 50 m above the intertidal zone to monitor movements of the anadromous Dolly Varden in spring, summer and fall, and periodically in the winter. It consisted of a wooden dam, which did not markedly alter the flow or level of water in the stream, but rather rechanneled it into a centrally located V-shaped notch. In the patch of this flow was the opening of a 1 m³ iron frame box covered with 6 mm hardware mesh. Fish were removed from the weir at least every 3 days, and usually more often, to count, measure, weigh and mark the fish captured before releasing them downstream.

The weir also acted as an effective barrier to upstream migrants, which usually remained in pools immediately below the weir, where they were captured by electrofishing or seining. These were then weighed, measured, marked and released upstream from the weir.

Density

Macroinvertebrates

Each month, three sections within each of the three previously described stream strata were randomly selected. A second randomized number was selected between 0 and 30 to correspond to metric distance by which to determine the exact location of three bottom samples (two near each bank and one in the stream center) within each section.

The bottom samples usually contained generous portions of mud, vegetation and gravel. Each was strained through a 0.5 mm square mesh wire screen. The macroinvertebrates were either sorted from the debris

immediately, or the entire sample was preserved in 4 percent formalin, with phloxine B added for later sorting.

The macroinvertebrates sorted from each bottom sample were placed in appropriately labeled glass vials containing 4 percent formalin. These were further sorted into generic and specific taxa by examining individuals with a binocular microscope at 20x. Jaques (1947), Edmondson (1959) and Usinger (1968) were used as references for identifying the macroinvertebrates. Factors of 10.74 and 43.10 were used to convert the number of individuals in Surber and Ekman samples, respectively, to individuals per square meter of stream bottom.

Fishes

Estimates of char density were made on a monthly basis. Rather than electrofishing the entire stream, only three randomly selected 30 m sections from each stratum were examined as representative of the population. Thus, estimates of char density in nine sections were made for each stream, monthly.

Both streams were small with a large segment of the population in Clevenger Creek known to be anadromous. It was estimated that 25 to 40 percent of the population could be marked. Thus, estimation methods most nearly suitable to these conditions were employed. These included:

1. the Schumacher-Eschmeyer method of mark and recapture (Ricker, 1958) and
2. the Zippin (1958) multinomial removal method.

Mark and Recapture. The Schumacher-Eschmeyer estimate was first thought to be most suitable in the small Amchitka streams, since this multiple census technique allows for monthly estimates of density when

samples contain about 25 percent marked fish. Estimates at monthly intervals were needed to calculate fish production in order to evaluate the long term effects of mud spills. An attempt was made to meet or approximate all of the assumptions behind this multiple census method (Lagler, 1952; Ricker, 1958):

1. marks on individual fish remain distinct and recognizable upon recovery,
2. marked fish become randomly mixed with unmarked fish,
3. marked fish suffer the same mortality as unmarked fish, and
4. recruitment or migration remains minimal or accountable.

Each stream was electrofished, and all of the fish captured were weighed and measured. Anchor tags⁴, serially numbered and corresponding to recorded weight and length, were attached to each char that measured over 150 mm SL. A different colored tag was used in each stream. The use of Floy tags on Dolly Varden was reported in southeastern Alaska by Armstrong and Blackett (1966). In the present study, the rapid, cartridge-fed applicator described by Dell (1968) was used. Smaller fish were marked by mutilation of fins; pelvic and adipose fins and combinations of these were severed with sharp surgical scissors. Fish from approximately 30 m of stream were collected before examining and releasing so that the marked fish were returned distributed among the unmarked fish. Individuals that appeared injured at release were recovered and sacrificed to prevent biased mortality among marked fish. Information on age, diet, fecundity and sex was gathered from these sacrificed fish.

⁴FD-67 anchor tags and standard Dennison tag gun from Floy Tag Manufacturing Co., 2909 N.W. Blakely, Seattle, Washington 98105.

Ricker (1958) presented the formula for the Schumacher-Eschmeyer method of population estimation as:

$$\hat{N} = \frac{\sum cm^2}{\sum mr}$$

where: \hat{N} = estimated population,

c = number of fish in the sample,

m = number of marked fish in the population, and

r = number of marked fish in the sample.

The 95 percent confidence interval (Ricker, 1958) was computed for each estimate.

The Schumacher-Eschmeyer method was satisfactory in Clevenger Creek as long as the fish weir remained operable. However, at certain times of the year, no personnel were on the island to maintain it, and the weir box was removed, allowing unknown numbers of fish to descend to sea or ascend the stream. This violated assumption 4 of the method above, making it necessary to reestablish initial marks in the population and begin a new mark and recapture program after every absence from the island. A method to yield point estimates was clearly needed, since the Schumacher-Eschmeyer method could not be used continuously.

Removal method. The small streams under consideration were electrofished efficiently enough to permit use of a removal method of population estimation. One was needed to provide confidence limits on a point estimate, a statistic that several regression methods (Leslie and Davis, 1939; Delury, 1947; Hayne, 1949; Dixon and Massey, 1951) do not provide.

The multinomial method of population estimation, as described by Zippin (1958), provides a point estimate with confidence limits. It is

based on the probability of capture for individual fish from multiple catches (three or more), and relies on the following assumptions:

1. mortality, immigration and emigration are negligible during catches,
2. the probability of being captured is equal for all individual fish,
3. sampling effort is the same during all catches, and
4. the probability of capturing individuals is constant from one catch to the other.

Estimates were made on 30 m sections of stream by electrofishing and holding the fish of each catch live in separate containers. From three to six catches were made on each section with no more than 1 hour elapsed between catches. The greater number of catches yielded better estimates and narrower confidence limits. An attempt was made to maintain a similar level of effort for each catch in a given section by using the same number of landing nets and workers.

After all catches were completed, the number of fish in each was recorded, and each fish was weighed, measured and released in the section of capture. Only the fish larger than 150 mm SL were tagged for data on movement and growth, while the smaller fish were returned unmarked.

The fish in each catch were segregated into age groups (by using previously established age and length relationships), and population estimates were made on each group by the method described by Zippin (1958):

$$\hat{N} = \frac{T}{(1-\hat{q}^k)}$$

where: \hat{N} = population estimate,

T = the total catch, and

$(1-\hat{q}^k)$ = estimated proportion of the population captured.

The 95 percent confidence interval (Zippin, 1958) was computed for each estimate. The sum of the catches of the three sections within each stratum constituted the data needed for the previously described method.

Age and Growth

Macroinvertebrates

Large numbers of individuals of each species of macroinvertebrate were periodically weighed and measured. Length and weight of individuals of each species were plotted against time to illustrate growth rate. Length-frequency histograms were used to determine the duration of each cohort of macroinvertebrate.

Fishes

Although scales have been used to age Dolly Varden (Wright, 1960), most investigators prefer the otolith method (Heiser, 1966; Armstrong, 1970; Wydoski⁵). This is because erosion and reabsorption of scale margins frequently occurs in anadromous salmonids, especially Atlantic salmon and sea-run trout and char (Crichton, 1935; Kim and Roberson, 1968). Aside from this problem, a high incidence of replacement scales was encountered in Dolly Varden from Amchitka.

⁵Personal communication with Dr. Richard Wydoski, Cooperative Fishery Unit, Utah State University, Logan, Utah 84322, September, 1973.

The age of Dolly Varden on Amchitka was determined by examining annual rings on the otolith, or the largest of the inner ear bones. The otolith bones of 627 char, collected from throughout Amchitka, were examined under binocular microscopy to establish (1) an otolith to body length relationship and (2) fish length at each annulus formation. Many of these otoliths were collected and examined by Nordmeyer (1974) in a life history study of Dolly Varden on Amchitka.

Standard length in millimeters and weight in grams were known for each fish before a mid-dorsal, vertical slit was made on the head to expose the internal head bones. Only the largest of the three pairs of otoliths, the sagitta, was removed with a pair of forceps. The thin, clear membranous sacculus around each otolith was rubbed off with the thumb and index finger, and each otolith was placed in 10 percent glycerine. Most otoliths became quite transparent when left in this clearing agent for about 24 hours. Otoliths were stored dry in labeled coin envelopes, when not immediately examined.

Some otoliths, especially those of younger fish, did not require clearing, but those with a thicker structure required grinding and polishing before clearing. This was done by mounting each on a wad of warm wax at the tip of a short dowel rod. The medial (inner) surface of the otolith was ground on moist, fine, black emery cloth until the furrow (sulcus acusticus) was only slightly evident. The otolith was then placed in the clearing agent.

All otoliths were examined in a water-filled petri dish atop a black background with a binocular microscope at 20x. The lateral (outer) surface of each otolith was viewed. Under reflected light

(light source above the otolith), the zones with a relative abundance of inorganic matter, or the growth zones, appeared white or opaque. The zones of relatively greater organic matter, or darker hyaline zones, represented the annuli. Unlike the otoliths of sockeye salmon (Kim and Roberson, 1968), the marine growth zones of Dolly Varden were not interrupted at the notches. The distinction between the two phases of the life cycle (freshwater and marine) was marked only by the relative distance between growth zones; marine growth zones and accompanying hyaline zones were much wider than the freshwater zones of early life.

The distance from the centrum of each otolith to the outer edge of each annulus was measured along the ventral lobe in micrometer units. Chugunova (1963) recommends measurement along the dorsal lobe instead, but in these char, this lobe was often fringed with closely spaced rings, which hindered distinction of annuli.

The relationship between otolith radius and fish standard length was illustrated by plotting the two parameters. The relationship represented by the scatter of points was best described by Carlander's third degree polynomial model:

$$L = b_0 + b_1R + b_2R^2 + b_3R^3$$

where: L = fish standard length in millimeters,

R = otolith radius in micrometer units, and

b_0 , b_1 , b_2 and b_3 = empirical constants.

A description of the mathematical calculation for this polynomial is presented by Anderson and Bancroft (1952), and use of the model in life history work is cited by many (Lagler, 1952; Sigler, 1953).

Once the relationship was described, the standard length of each fish at each annulus formation was backcalculated. The average backcalculated length for the entire sample at each annulus formation was then compared against actual fish lengths to determine if Rosa Lee's Phenomenon was operative. If it existed, backcalculations of length tended to be smaller than actual lengths at a given age, the older the fish from which they were computed. A summary of the possible causes for this are presented by Ricker (1968).

Production

Production is the amount of biomass elaborated by a group of organisms for a specified time, regardless of whether or not all of the organisms are still present at the end of that time (Ivlev, 1945; Gerking, 1962). The energy tied up by this process flows through distinct trophic levels. Its most obvious products are successive stocks of organisms that typically increase in individual size as they decrease in total bulk (Odum, 1971).

The magnitude of a perturbation on an aquatic community may be evaluated by following the production of fishes and invertebrates. An increase or decrease in production may reflect seasonal variation, maturation of the community, or the effect of an outside disturbance. This change may be community-wide or it may occur only in specific trophic levels. Production is often more desirable than instantaneous summation of numbers or biomass of organisms (standing crop), for evaluating perturbations, because it considers changes in biomass over time and the rate at which these changes occurred. Since standing

crop ignores turnover rate, it does not necessarily bear a close relationship to production (Carlander, 1953; Odum, 1962; Margalef, 1963).

Of the four methods available for computing production (Waters and Crawford, 1973), the instantaneous growth method was used for both macroinvertebrates and fishes. Production of these primary and secondary consumers was measured before and after the perturbation. A history of recolonization, or the density of various species over time, accompanied these production estimates. The 95 percent confidence interval for estimates of production was calculated by the methods of Ricker (1958).

Macroinvertebrates

The total lengths of all Chironmus riparius in each bottom sample were measured and the individuals segregated into 1 mm size groups. Large numbers of these were weighed periodically to provide wet and dry weights of individuals. The instantaneous growth method ($P = G\bar{B}$), used to calculate production of each cohort, is described in the following section on production of fishes.

Fishes

Monthly production of Dolly Varden in the streams was estimated for each age group or cohort by the instantaneous growth method. The summation of these estimates yielded an estimate of annual fish production. The steps for calculating production, clearly given by Ricker (1958), involve gathering:

1. numerical densities and weights of organisms at monthly intervals and
2. rates of growth and mortality for these same intervals.

The total dry weight biomass elaborated monthly by each cohort in each study stream was determined by the mathematical model of Ricker (1946):

$$P = G\bar{B}$$

where: P = production (dry weight) during time t ,

G = instantaneous rate of increase in weight and

\bar{B} = mean biomass during change in time t .

The term G , or instantaneous growth rate, was evaluated in terms of weight increase. The growth of Dolly Varden and Chironomous riparius was exponential, so the coefficient G , was estimated as:

$$G = \frac{\log_e \bar{w}_2 - \log_e \bar{w}_1}{\Delta t}$$

where: \bar{w}_1 and \bar{w}_2 = mean weights of organisms at time t_1 and t_2 , respectively.

A number of well known studies have employed the principle of production to evaluate fish stocks (Allen, 1951; Gerking, 1962; Cooper, Hidu, and Anderson, 1963; Chapman, 1965), but in only selected papers has this approach been used to evaluate the magnitude of man's intervention on a biotic community (Hunt, 1966).

Estimating fish production in stream communities of Amchitka represented a perplexing problem. Most of the fish population in Clevenger Creek was anadromous and much of the body tissue of adults was assimilated at sea. It was difficult to assess precisely the amount

of biomass assimilated at sea, and that assimilated in the stream without monitoring movement of fish. A great deal of effort was, therefore, expended on operating and maintaining the two-way fish weir to monitor migration patterns and numbers of fish moving. In computing production of anadromous populations, only that biomass assimilated by the juveniles in the stream was considered. Thus, the loss of gonadal weight during spawning was not a problem in determining instream production, since the adults were not considered in this estimate.

Fecundity

The gonads of sacrificed female char were extracted via a ventral incision, and the displacement volume of a 100 egg sample determined. The number of eggs in each gonad was then estimated as the product of the volumetric conversion factor found for the 100 eggs and the total volume of eggs in the gonad. The sum of the eggs in the two gonads was considered total fecundity for that fish. Mean fecundity for the entire sample was then calculated, and so was the correlation between fish standard length and the number of eggs carried. The 95 percent fiducial limits for this displacement method can be expected to be about 3 percent (Burrows, 1951).

Species Diversity

The diversity of a biotic community can be expressed mathematically as a ratio between numbers of species and individuals. This species diversity index permits summarization of large amounts of information

about numbers and kinds of organisms. Margalef (1958) first proposed analysis of mixed species populations by using methods derived from the information theory expressed by the Shannon-Weiner function:

$$\bar{H} = - \sum n_i / N \log_e n_i / N$$

where: \bar{H} = species diversity index,

n_i = importance value of each species in terms of numbers,
production, or biomass and

N = total of importance values.

Diversity is equated with the uncertainty that exists concerning the species of an individual selected at random from the population; the more species present in a community and the more equal their abundance, the greater the uncertainty or information, hence the greater the diversity. The information theory, therefore, is based on a measure of uncertainty and has been shown to be a reliable measure of the diversity of some biological communities (Margalef, 1958; Wilhm and Dorris, 1968; Odum, 1971). The species diversity index, using this information theory, is advantageous in quantifying the status of the community over simple measures of species abundance, since it does not require specific taxonomic identification of individuals, but rather only recognition of distinct groups. The units describing these organisms must be standardized as numbers for individuals of similar size and function, or as biomass or production for individuals of different trophic levels and sizes, or both. In the present study, numbers of macroinvertebrates was used as importance values.

Benthic macroinvertebrates are particularly suited for analyzing the trend in species diversity of a perturbed community (Richardson, 1928; Gaufin and Tarzwell, 1956; Wilhm, 1970). Bottom organisms have little motility by which to escape deleterious effects of a substance. In most aquatic communities, benthic organisms are intermediary in the food chain, providing the main energy source to important fish species. Although only one or two species of these invertebrates may be considered dominant in the community, invertebrates often represent a large number of species with many individuals in each to lend to greater diversity and thus, better information about the community (Hynes, 1970).

RESULTS

Response of Clevenger Creek to Mud Spills

Most macroinvertebrates and fishes in Clevenger Creek survived a small spill in January 1968. Little data are available from before and shortly after this unexpected incident, but those which are, show little discrepancy in species and densities of macroinvertebrates and fishes.

The second spill which persisted from mid-May to mid-June 1969, was more deleterious to aquatic populations than the first, as is demonstrated by densities of macroinvertebrates in 1969 (Table 1). The response of these organisms is further seen in densities recorded for 4 of 5 years after the spill. Densities of the immature midge (Chironomus riparius) and of juvenile Dolly Varden are isolated to illustrate the response of the two more abundant species in the community before and after the spill (Figure 5); point estimates and confidence intervals are presented in Table 9. (See appendix.)

Density

Macroinvertebrates. Clevenger Creek was nearly devoid of macroinvertebrates from June to December 1969 (Table 1). The maximum density of individuals for this 7 month period was 163 m^{-2} . Most of these organisms were oligochaetes from samples near the stream mouth taken among marine algae and debris washed into the stream by high tides. Although a few midges, especially the species C. riparius, may have survived the mud spill, the low densities of organisms at this time most likely represent drift from unaffected areas upstream.

Table 1. Densities of macroinvertebrates in Clevenger Creek, expressed as the mean number of individuals per square meter, before and after mud spills from the Milrow test site.

TIME AND EVENT	1 ^a	2	3	4	5	6	7	8	9	10	TOTALS
1968											
Jan: First Spill											
Jul	4,687	68	102	3	986	16	432	0	0	0	6,295
1969											
May-Jun: Major Spill											
29 Jun	0	0	0	0	0	0	0	0	0	0	0
29 Jul	13	14	0	0	0	0	0	0	0	0	27
26 Aug	0	0	0	0	0	0	0	0	0	0	0
15 Sep	54	0	0	0	0	0	0	0	0	0	54
2 Oct: Milrow											
3 Oct	44	0	0	0	118	0	0	0	0	0	163
18 Dec	4	1	0	0	82	0	0	0	0	0	87
1970											
10 Apr	58	1	0	0	132	0	0	0	0	0	181
17 Jun	1,120	1	51	0	8	0	0	0	0	0	1,180
23 Jul	898	1	63	1	106	26	2	0	0	0	1,096
21 Aug	1,395	2	12	0	99	0	0	0	0	0	1,507
29 Sep	1,426	6	1	0	105	16	1	0	0	0	1,554
19 Nov	590	4	0	0	86	12	0	0	0	0	693
1971											
28 Jan	96	1	0	0	54	0	0	0	0	0	151
20 Mar	136	0	29	0	25	0	0	0	0	0	190
10 Jun	349	1	38	0	81	0	64	0	0	0	533
31 Jul	4,523	3	43	1	1,214	0	691	0	0	0	6,475
19 Aug	5,203	17	63	0	986	0	589	0	0	0	6,858
9 Sep	5,386	19	0	0	669	0	510	0	0	0	6,584
23 Oct	2,653	1	0	52	122	4	11	0	0	0	2,843
6 Nov: Cannikin											
12 Dec	892	1	0	0	282	16	70	0	0	0	1,261
1972											
16 Mar	203	10	32	1	63	0	78	14	0	0	401
1974											
28 Aug	3,214	27	145	0	91	0	0	110	3	3	3,593

^a code for organisms:

1 = Chironomus riparius

2 = Chironomus sp. and Hydrobaenus sp.

3 = Pseudocloeon sp.

4 = Limnophilidae

5 = Oligochaeta

6 = Sphaeridae

7 = Gnorimosphaeroma lutea

8 = Leptoceridae

9 = Hyallela sp.

10 = Simuliidae

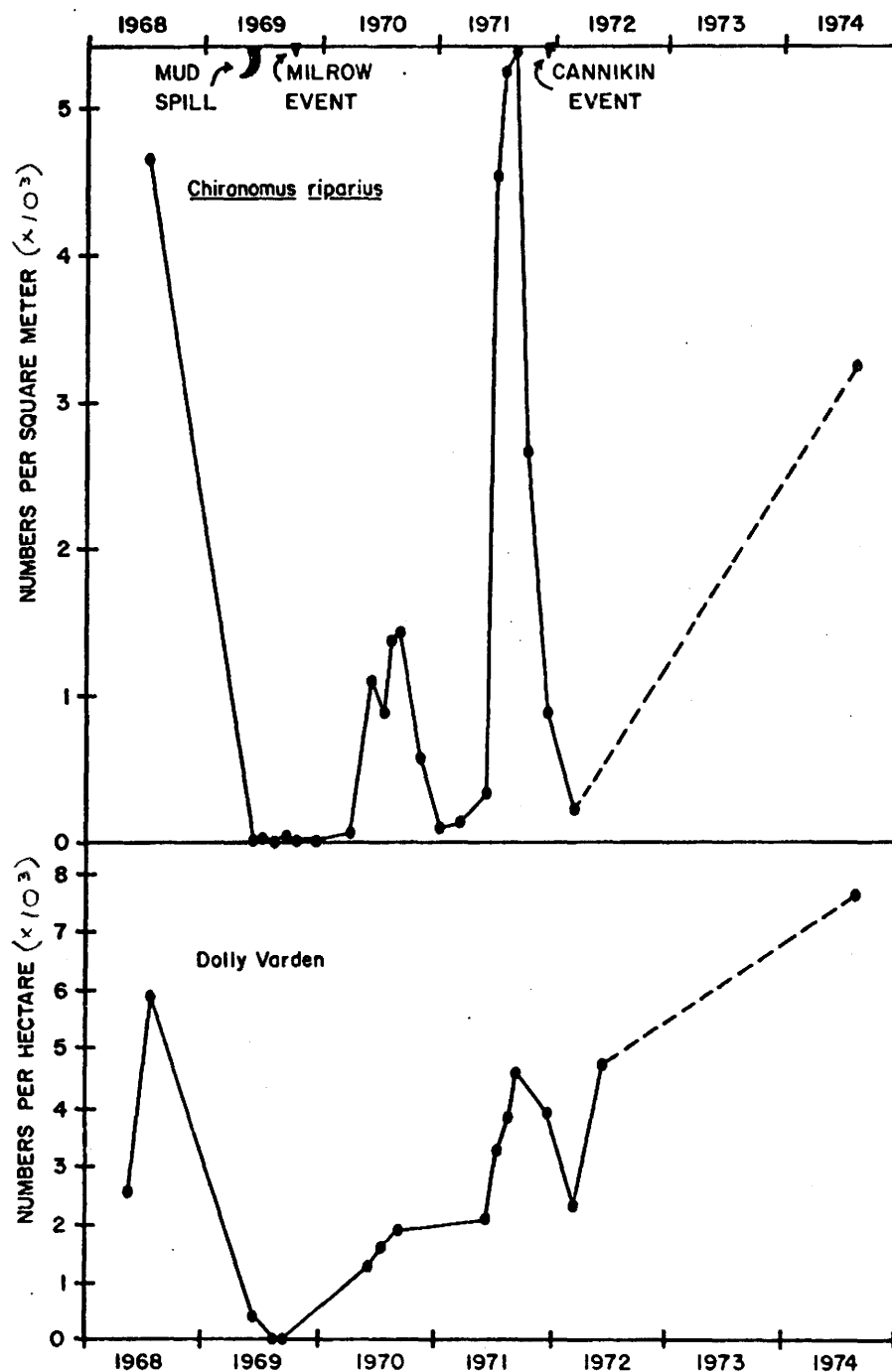


Figure 5. Densities of immature *Chironomus riparius* and juvenile Dolly Varden in Clevenger Creek, expressed as numbers per square meter and numbers per hectare, respectively. A time scale is provided to relate the densities of the two populations to the mud spill and the detonations.

An absolute increase in the number of macroinvertebrate species and their densities was observed after April 1970. The oligochaetes were found as before, usually associated with benthos of the stream mouth. The appearance of the mayfly Pseudocloeon sp., an organism with high oxygen requirements, was an excellent indication that much of the pollutant was being flushed from the stream. Since this species of mayfly is univoltine and emerges and oviposits in late summer, nymphs appeared in samples only in spring and summer.

Population estimates of C. riparius in the summer of 1970 showed at least a twenty-fold increase over those of 1969 (Figure 5). Larvae and pupae of this midge first entered the samples in June, although numbers were not highest at this time because sampling equipment allowed some of the smallest midges to escape, while others became entangled in debris and remained in the sample. After a maximum density of $1,426 \text{ m}^{-2}$ in September, emergence occurred, and natural reductions in larvae and pupae were seen. The maximum estimate is probably considerably less than the real density, considering that there was mortality of the midges before they were large enough to enter the sample.

Densities of macroinvertebrates in 1971 far surpassed those of 1970, further demonstrating the recovery of Clevenger Creek (Table 1). The variation in densities of oligochaetes and isopods (Gnorimosphaeroma lutea) is due to the clumped distribution of both forms in debris near the stream mouth, from which some random samples were taken. Estimates of Pseudocloeon sp. in July 1971 were still less than half of those of July 1968, before the major spill.

Trends in the density of C. riparius in 1971 followed the same pattern as those of the previous year, indicating that most emergence occurred in September and October (Figure 5). The estimate of 4,523 m^{-2} in July 1971, was very similar to that of 4,687 m^{-2} , recorded in July 1968, indicating that this species had reached its pre-spill density in just 2 years. However, an additional estimate in August 1974 revealed a lower density than that recorded in August 1971.

When maximum densities of C. riparius, in July, August and September of 1969, 1970, 1971 and 1974 (four separate cohorts) are considered (Figure 6), the population is observed to reach an asymptote and then decrease. Unfortunately, no data were available from 1972 and 1973 to determine the asymptotic level and observe the fluctuations in the population afterward. The rapidity with which this species re-established itself is evident from the exponential portion of this logistic growth curve. Since few of the other macroinvertebrates recovered as rapidly, individuals of C. riparius apparently could occupy niches vacated by other organisms and attain a temporarily higher population level. However, competition and predation appears to have depressed the population, as the density of sympatric species and fishes increased in 1973 and 1974.

Fishes. The population of Dolly Varden in Clevenger Creek responded much like that of the macroinvertebrates to the two mud spills (Figure 5). Only those fish that resided in the stream year around, individuals of the age groups 0 to II and some of those in age groups III through V, were considered. Migration of the anadromous adults caused large seasonal fluctuations in numbers that were undesirable

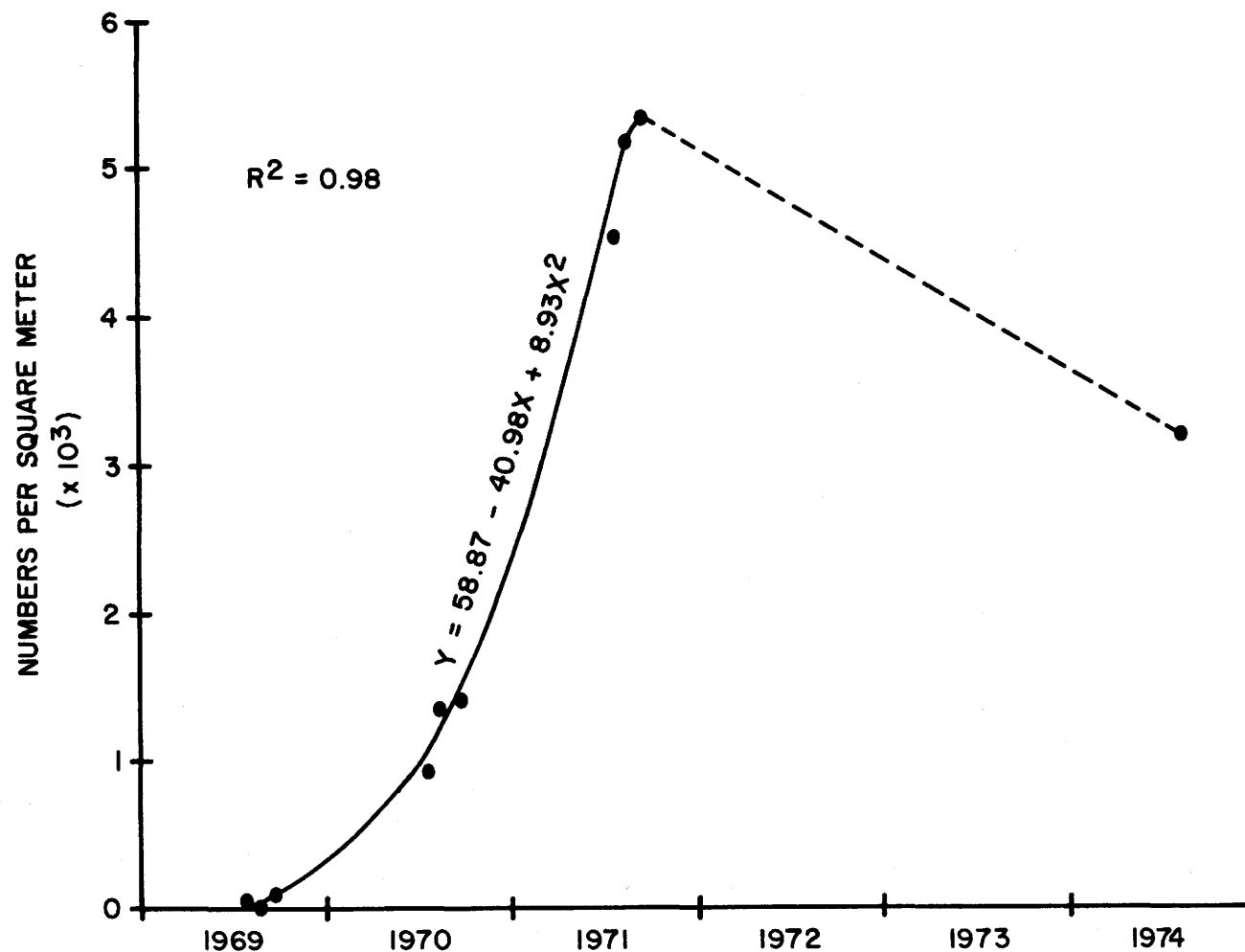


Figure 6. The logistic growth curve of the population of immature Chironomus riparius in Clevenger Creek after the mud spill. Only the three months (July, August, and September) in which the species was most abundant each year are considered. Samples from four cohorts are shown for this univoltine species.

in this portion of the analysis. The numbers of adults are considered later in this presentation. The population of the entire 1,886 m of stream affected by the spill was expressed as numbers per hectare. Since the average stream width was 1.01 m, the total stream area was $1,905 \text{ m}^2$. Thus, a multiplier of 5.25 was used to convert stream density to number per hectare, since 1 ha equals $10,000 \text{ m}^2$.

The discrepancy between the first and second estimates indicates a total reduction of about 360 juvenile char after the first spill. This is not interpreted as a result of the spill; natural winter mortality and a failure of sampling to capture individuals of the new 1968 year class were responsible for the lower second estimate. Therefore, the May 1968 estimate of juveniles represents a minimum estimate for pre-spill conditions. The subsequent estimate in July 1968 includes individuals of the new year class before extensive natural mortality, but excludes the smolts that migrated to sea in June. Nevertheless, this represents a maximum population estimate of juveniles before the perturbation.

The large reduction in Dolly Varden in June 1969, and the reduction of macroinvertebrates, demonstrated the marked effect of the second spill on individuals of the aquatic community. The persistence of the spill from mid-May to mid-June 1969, during a period of low stream discharge (Figure 2), allowed fuel oil to incorporate itself into stream mud and vegetation, leaving the stream devoid of Dolly Varden throughout the summer of 1969.

Population estimates in June, July and August 1970 ranged from 236 to 344 juveniles. Concentrations of these fish in the upper study area indicated that the majority immigrated from unaffected areas

upstream and from a tributary. Some young of the year from successful redds established in October 1969 were included in this estimate. The fry recovered from near these same redds in June and July 1970 were gorged with larvae of Chironomus sp.

Concentrations of char near the stream mouth also indicated that some 3 and 4 year old fish ascended the stream from the intertidal zone. These were fish that either descended from adjacent unaffected streams or those from Clevenger Creek, that failed to stray far from its mouth.

Population estimates of char in 1971 were consistently nearly twice as high as those of each corresponding month sampled in 1970. Much of this repopulation was by the immigration of juveniles from unaffected areas and tributaries of the stream and from the intertidal zone. A strong 1971 year class of Dolly Varden was represented in July, August and September 1971, when the population reached a high of 874 fish. Seaward descent of some maturing individuals of the age groups III and IV, combined with natural mortality, yielded lower estimates in December 1971 and March 1972 (Figure 5). This reduction is not believed to be a result of the Cannikin event of November 6, 1971.

The June 1972 estimate of 898 juvenile char included only a few individuals of the 1972 year class, because these fish were too small to sample at the time. Nevertheless, a rapid recovery was indicated only 3 years after the major spill, most of which is attributed to immigration. Two years later (August 1974), the estimate of juvenile Dolly Varden was 1,464. This is a higher estimate than that made in July 1968, before the major mud spill; 1,137 juveniles. Like the popu-

lation of macroinvertebrates, that of Dolly Varden probably underwent extensive fluctuations around some mean level of carrying capacity between the sampling periods June 1972 and August 1974.

In late August 1970, nine adult pink salmon established four successful redds in Clevenger Creek. The eggs of these were eyed by mid-November and hatched in March 1971. As adults, these fish returned in August 1972 at the same density as their parents, as did the progeny of these in August 1974. No adult pink salmon were observed in Clevenger Creek in 1969, 1971 or 1973. Island-wide estimates of spawning pink salmon these 3 years were also low (Neuhold, Helm, and Valdez, 1974).

Threespine stickleback, which were rare in Clevenger Creek before the spill, were not found again after the spill.

The Milrow detonation of October 2, 1969 apparently did not seriously hamper the recolonization of Clevenger Creek. For 2 days after the detonation, the stream was heavily burdened with mud and silt loosened by the shock, but no dead organisms were observed anywhere in the stream. Furthermore, no effects were observed either on the terrain or biota of Clevenger Creek after the Cannikin event of November 6, 1971, which took place about 9 km away. Its effects on White Alice Creek will be reviewed later.

Growth and biomass

Growth rates of both C. riparius and Dolly Varden did not appear to be affected by the mud spills. The post-spill biomass of most of the macroinvertebrates in Clevenger Creek, except for C. riparius,

was minute. The trends in biomass of this midge and juvenile Dolly Varden, expressed as grams of dry weight per square meter of stream bed, are used to illustrate the response of the two consumer levels to the mud spill (Figure 7). Confidence intervals for these point estimates are presented in Table 10. (See appendix.)

Macroinvertebrates. The growth of C. riparius was less than exponential from January to mid-summer (Figure 8). Climatic conditions probably depressed growth in the winter, even though winters on Amchitka are quite mild; ice and snow cover rarely persist on streams like Clevenger for more than a week at a time. Water temperature in the stream ranged from about 1 C in January to about 11 C in September (Figure 16, see appendix). Growth of C. riparius accelerated in August and September, just prior to an extended period of pupation and emergence lasting from late August to early October. This is a time on Amchitka when high velocity winds are less frequent and chances of oviposition probably greatest.

Weights of individual midges before and after the mud spill indicate that growth rate did not differ significantly ($\alpha = .05$). Variation in biomass between the 1970 and 1971 year classes was a function of density instead of differential growth rate brought about by the pollution.

The biomass of C. riparius increased sharply 1 year after the major mud spill (Figure 7). The biomass of this first cohort of the recovery period was first detected in June 1970, and it reached a maximum of 2.08 gm m^{-2} in September. Emergence then occurred and biomass decreased to nearly zero by mid-winter. The mean biomass standing crop for 1970 was $0.90 \text{ gm m}^{-2} \text{ yr}^{-1}$.

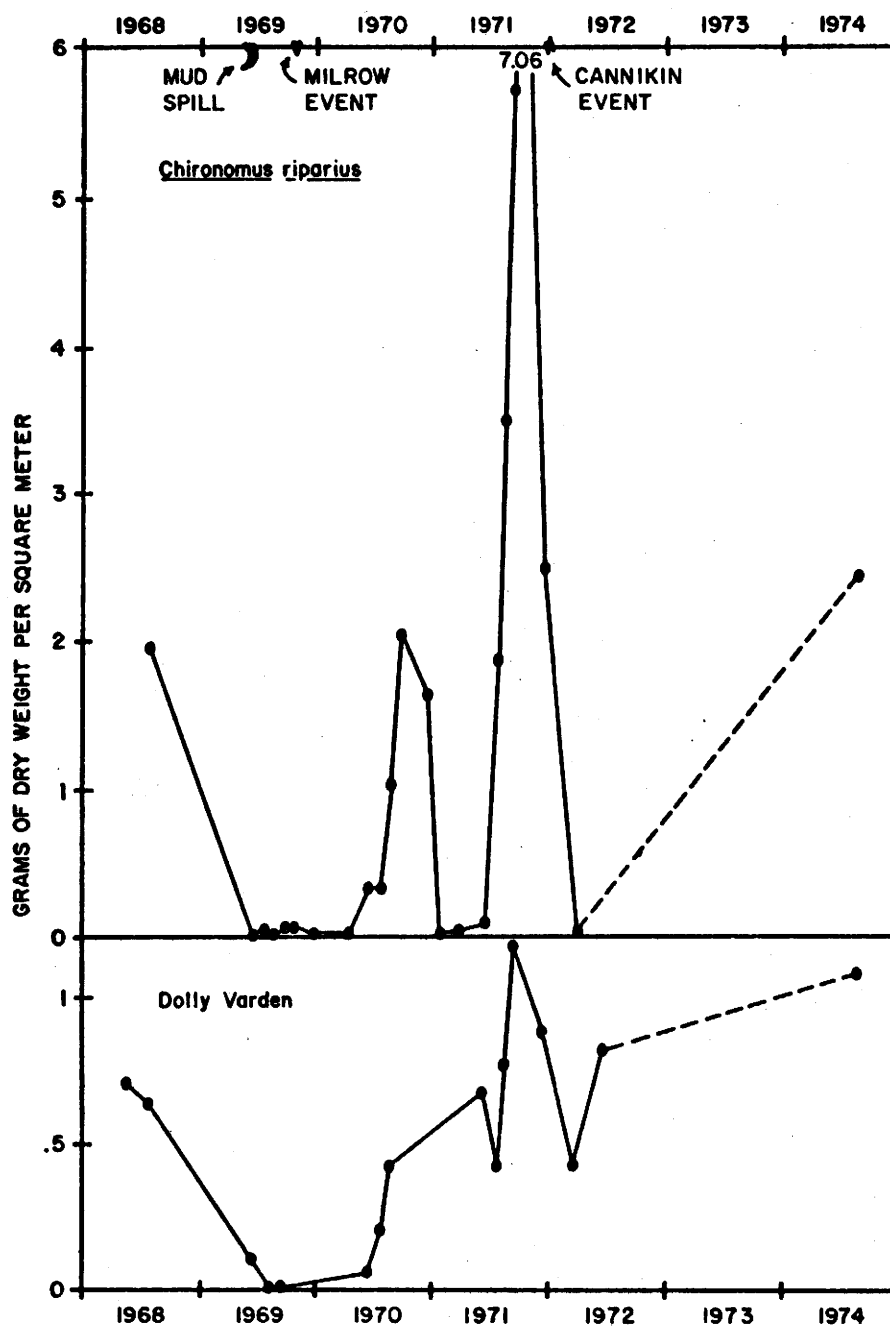


Figure 7. Standing crop of immature *Chironomus riparius* and juvenile Dolly Varden in Clevenger Creek, expressed as grams of dry weight per square meter of stream. A time scale is provided to relate the standing crops of the two populations to the mud spill and the detonations.

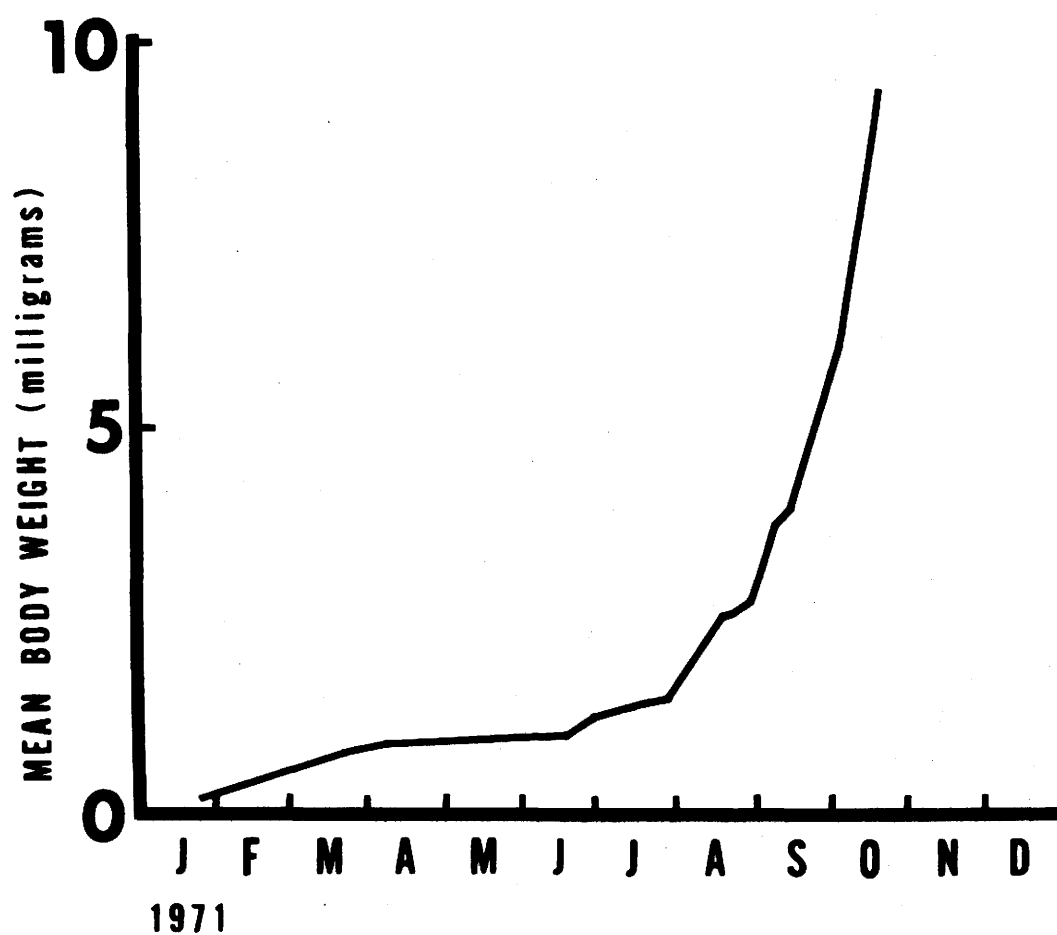


Figure 8. Growth of *Chironomus riparius* from Clevenger Creek as represented by mean individual wet weight at monthly intervals.

The biomass of C. riparius in 1971 similarly increased in samples after June, reaching a maximum of 7.06 gm m^{-2} in October. This maximum biomass for 1971, as well as the average annual standing crop of $2.60 \text{ gm m}^{-2} \text{ yr}^{-1}$, was about three times that of the 1970 estimates.

Fishes. No significant difference (linear regression, $\alpha = .05$) existed between the slopes describing the growth rate of Dolly Varden before (September 1967) and after the mud spill. A curve for these two periods combined (Figure 9) shows that growth in the first 3 to 4 years of life was relatively slow, when compared to that of the mature sea-run fish past age group IV. The growth rate of those juveniles not migrating to sea until age group V was considerably less than that of the sea-run fish of the same age. However, once migration occurred, growth rate paralleled that of the sea-run fish (Figure 9).

Average monthly instantaneous growth rate (G) for juvenile Dolly Varden in the stream and mature fish at sea (June, July and August) was 0.11 and 0.60, respectively (Table 11, see appendix). However, G for the mature fish during the 286 days of their stream residence (during spawning) was -0.05. Except for the growth of sea-run fish during their 73 days at sea, G was highest in age group 0; maximum rates occurred between June and August (Figure 10). The monthly G of the age group I fish appeared bimodal; maxima occurred April to June and July to September. The monthly instantaneous growth rates of juveniles of the age group II through V were very similar, with maximum rates occurring between July and August.

Average life expectancy for Dolly Varden on Amchitka was 9 years; the high rates of growth and stress from repeated spawning ascents probably suppressed life expectancy.

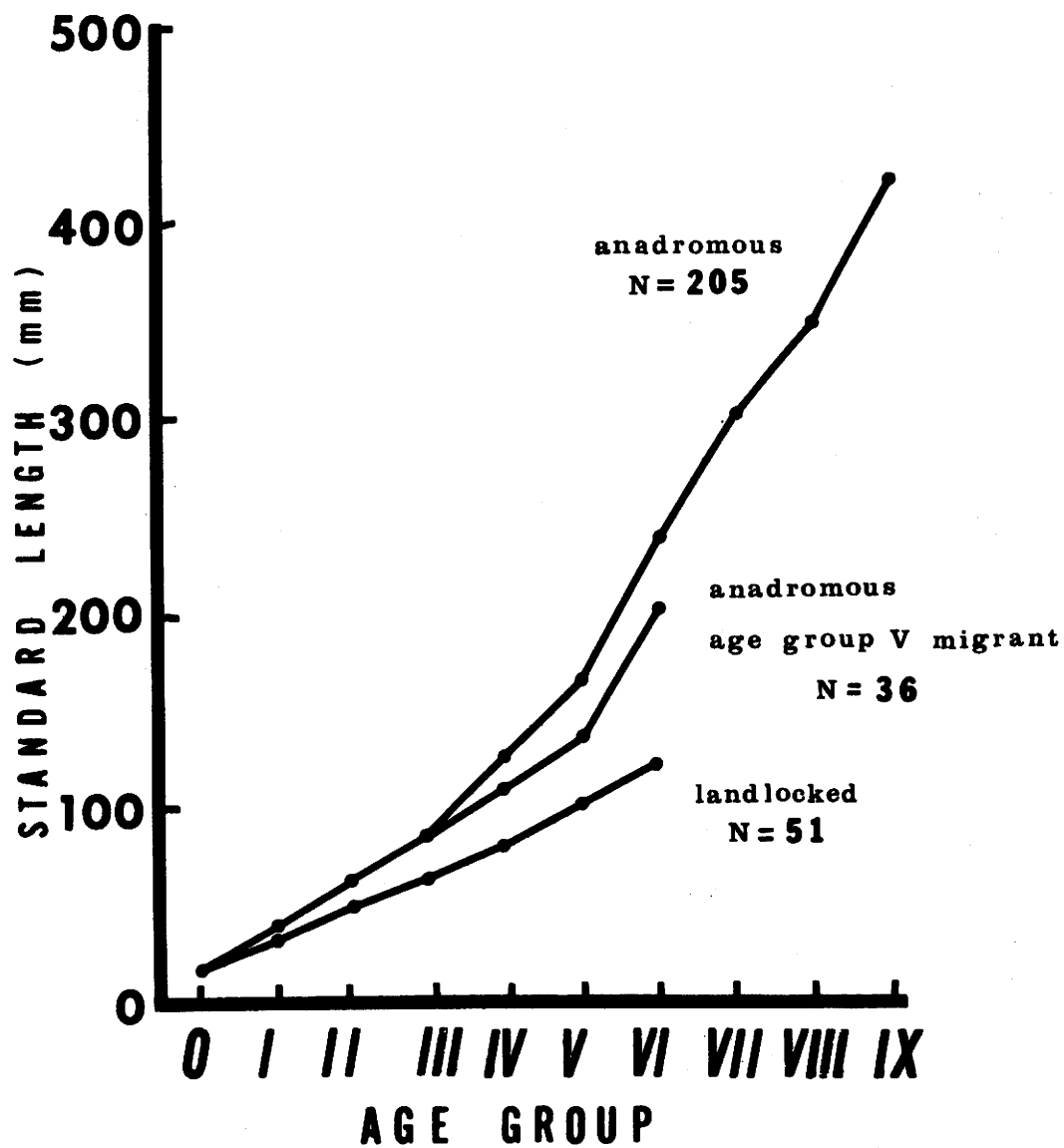


Figure 9. Growth of anadromous and landlocked Dolly Varden from Clevenger and White Alice Creeks, respectively (n = sample size).

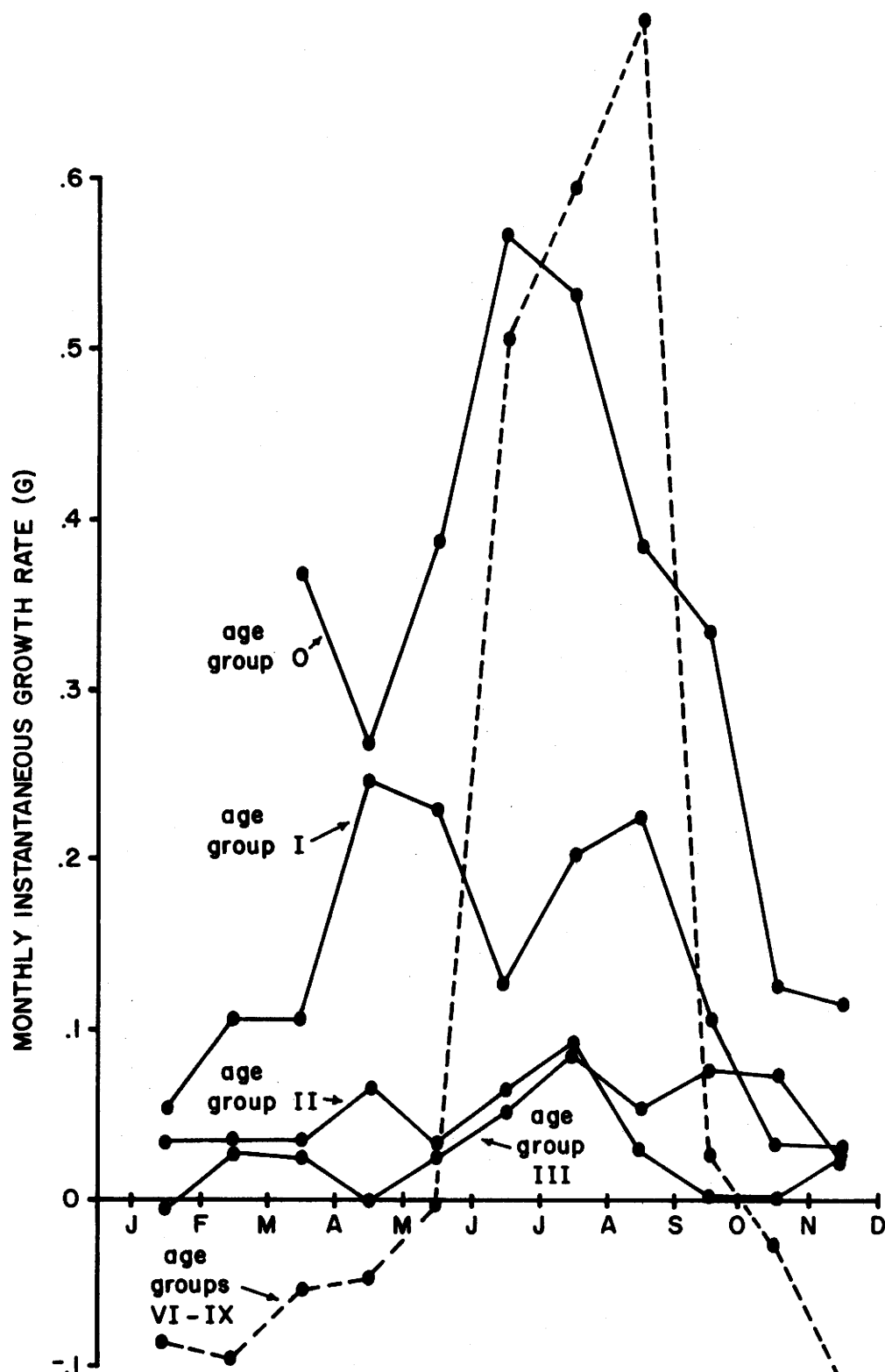


Figure 10. Monthly instantaneous growth rates (G) of juvenile (0-III) and adult (VI-IX) Dolly Varden in Clevenger Creek. Instantaneous growth rates of age groups IV and V are not shown since these nearly parallel those of age group III.

Little natural reproduction by Dolly Varden occurred the fall of 1969. With the elimination of resident fishes by the 1969 spill, a maximum standing crop biomass of only 0.42 gm m^{-2} was recorded in 1970 (Figure 7). About 76 percent of this biomass was from immigrating fish.

Additional immigration, high survival of the meager 1970 spawn, and growth by individuals, yielded a greater maximum standing crop of 1.17 gm m^{-2} in September 1971. Slight decreases in biomass of Dolly Varden in spring and early summer 1972 resulted from natural mortality, and smoltification and seaward descent of the 3, 4 and 5 year old fish, most of which originally immigrated from outside of the study area.

Production

Production of both C. riparius and juvenile Dolly Varden was markedly suppressed by the mud spill of early 1969 because of the effect on population densities, and not as a result of depressed growth rates. However, production was rapidly reinstated after the pollutant was flushed. Production estimates of both species are presented in Table 12. (See appendix.) Computations of production for C. riparius are provided in Table 13 (See appendix.) and those for Dolly Varden are provided in Tables 14 through 24. (See appendix.) Estimates of C. riparius production beyond 1971 were not calculated because of the long interval between collections.

Macroinvertebrates. Total annual production of C. riparius before the 1969 mud spill was 8.12 gm m^{-2} , dry weight (Figure 11). This was comparable to the annual estimate of 9 gm m^{-2} for midges (dominated by C. riparius) in an adjacent unaffected stream (Neuhold, 1971). Production in 1969, prior to, during, and after the spill, was 0.07 gm , most of which resulted from drifting individuals.

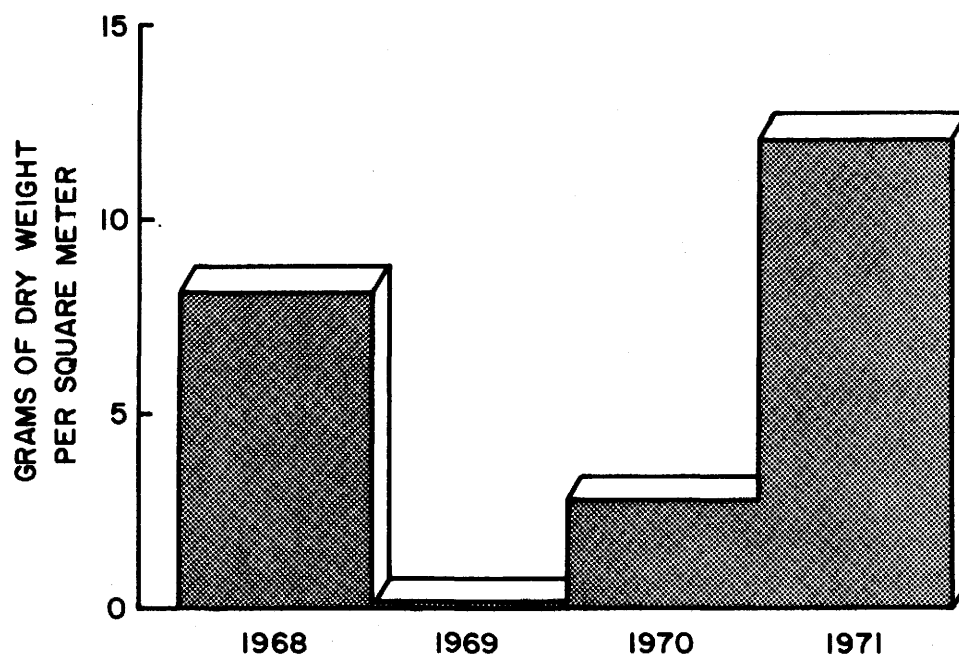


Figure 11. Production of Chironomus riparius in Clevenger Creek before and after the mud spill, expressed as grams per square meter.

Total production in 1970 (2.84 gm m^{-2}) occurred in the period from June to December. Although there was a large contingent of drifting individuals, most hatched from eggs deposited in the stream by immigrants of the previous year. Most production in 1971 also occurred from June to December, but at a much higher level than either previous year. The total production in 1971 (12.01 gm m^{-2}) probably exceeded the pre-spill estimate because of the sparse population of other macroinvertebrates and fishes to provide little competition and predation.

The production to biomass ratio (P/B) for C. riparius before the mud spill was 2.66 (Table 2). This ratio was considerably less than 1.00 in 1969, when the effect of the mud spill was most evident. In 1970 and 1971, P/B ratios were 3.16 and 4.62, respectively, indicating a proportionally greater level of production than standing crop as the community recovered from the spill.

Fishes. The annual production of juvenile Dolly Varden (age groups 0 - V), before the mud spill was 40.21 kg ha^{-1} , dry weight, or about 145 kg ha^{-1} , wet weight (Table 3). As expected, this annual production was highest in the age group 0, although, production of age group II exceeded that of age group I (Table 24, see appendix; Figure 12). Production of the age groups III through V was somewhat suppressed by natural mortality and seaward emigration (although most Dolly Varden smoltified as age group IV, many were observed to move to sea as age groups III and V). Juveniles immigrating from above the study area and from the intertidal zone accounted for less than 2 percent of this pre-spill production (Figure 12). These juveniles belonged to the age groups II through V, which immigrated into the study area during a natural

Table 2. Production to biomass ratios (P/B) for Chironomus riparius in Clevenger Creek. Production and biomass are expressed as grams of dry weight per square meter.

	1968	1969	1970	1971
TOTAL ANNUAL PRODUCTION:	8.12	0.07	2.84	12.01
AVERAGE STANDING CROP:	3.05	0.27	0.90	2.60
P/B RATIO:	2.66	0.26	3.16	4.62

Table 3. Production to biomass ratios (P/B) for juvenile Dolly Varden in Clevenger Creek. Production and biomass are expressed as kilograms of dry weight per hectare. This dry weight is converted to wet weight when multiplied by a factor of about 3.6.

	1968	1969	1970	1971	1972
TOTAL ANNUAL PRODUCTION:	40.21	11.28	11.13	42.45	43.58
AVERAGE STANDING CROP:	12.61	2.00	4.11	12.38	12.01
P/B RATIO:	3.19	5.65	2.71	3.43	3.63

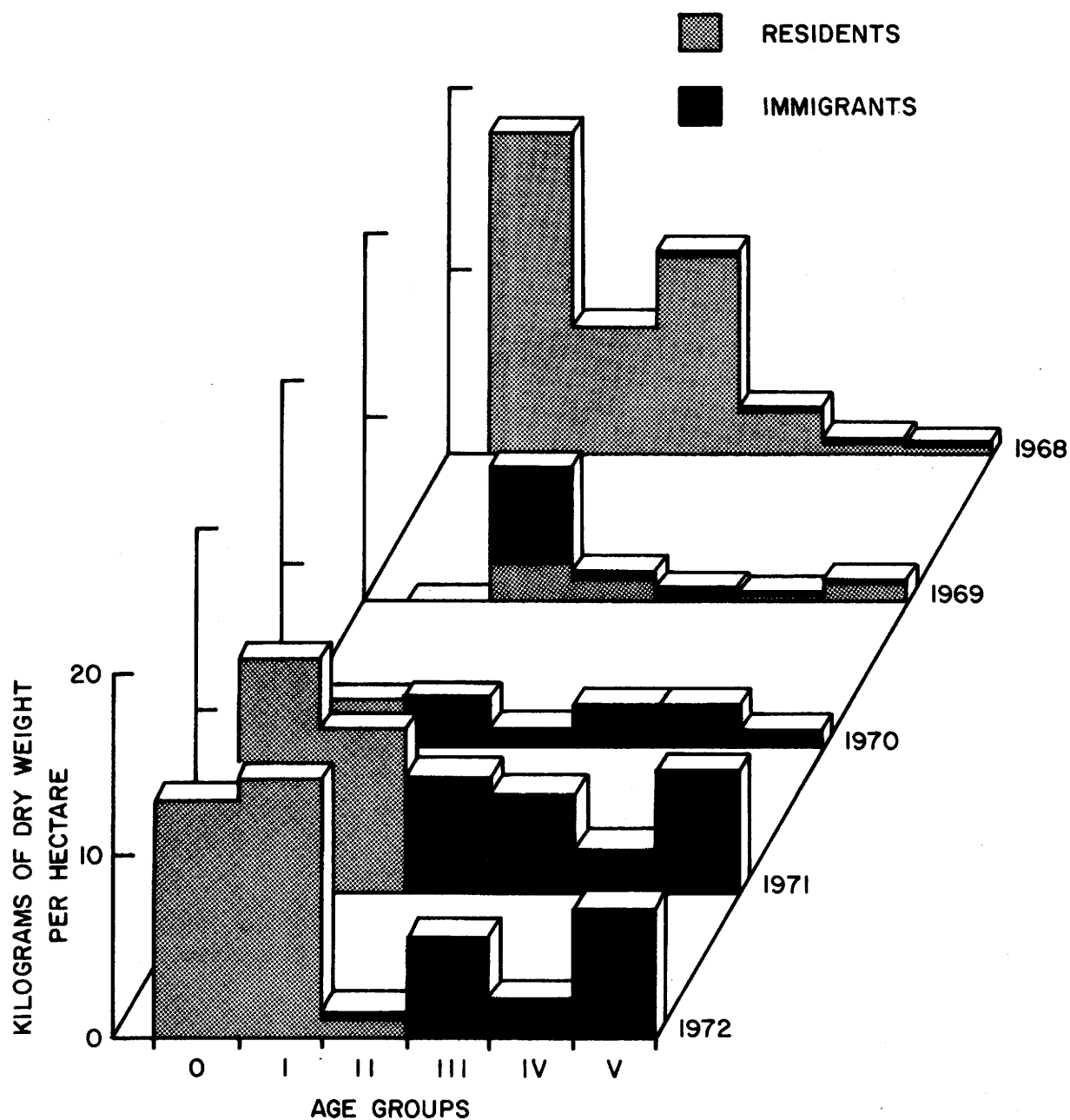


Figure 12. Production of juvenile Dolly Varden in Clevenger Creek before and after the mud spills, according to the fish hatched and residing in the study area (residents) and those immigrating from outside of the study area (immigrants).

descent prior to and during smoltification. Similar movement by juveniles was observed in other Amchitka streams (Nordmeyer, 1974).

Total production of Dolly Varden in 1969 was only 11.28 kg ha^{-1} , all of which occurred before the spill, in mid-May 1969. The study area was devoid of fish from June 1969 to June 1970, except for some adults returning to spawn in October 1969. The success of this spawning effort was low, resulting in a meager 1970 year class (the year class of eggs deposited in November and December and hatched in March of the following calendar year is designated by the year in which the fish hatched).

Over 77 percent of the 11.13 kg ha^{-1} produced by juvenile Dolly Varden in 1970 was by immigrants; fish which moved into the polluted area from unaffected areas of the stream. Only the age group 0 (the 1970 year class) was inherent to the study area. The higher success by spawners in 1970 than in 1969 yielded a sizeable 1971 year class, which contributed significantly to the repopulation of the stream via natural reproduction. Also, low mortality of the 1970 year class resulted in a high level of production by those fish of age group I in 1971. Nevertheless, immigrants in 1971 still accounted for over 48 percent of the annual production of 42.45 kg ha^{-1} . In 1972, the 1971 year class (age group I) maintained its strength and, together with the 1972 year class (age group 0), dominated fish production in Clevenger Creek. A high mortality of the age group II (1970 year class) was observed in 1972. Immigrants this year accounted for only 37 percent of the annual production of 43.58 kg ha^{-1} .

The observed influx of immigrants into the study area was very marked in 1970 and 1971, a time in which the population in the study area was depleted by the mud spill. This immigration appears to be a result of natural downstream movement by juveniles, many of which remained in the affected area and occupied vacant habitats.

The high rate of turnover ($P/B = 3.19$) in Dolly Varden, observed in 1968 indicates that Clevenger Creek is an evolutionary immature system (Table 3). The high P/B ratio of 5.65 in 1969 resulted from a depleted population, and is probably not a reliable ratio. The depressed P/B ratio of 2.71 in 1970 can be attributed to the predominance of immigrating fish of age groups I through V, which exhibited relatively slower rates of growth than the individuals of the less abundant age group 0 (Figure 10). In 1971 and 1972, the age groups 0 and I, which exhibited the highest rates of growth, dominated density and thus production. The P/B ratios of 3.43 and 3.63 revealed that production exceeded standing crop, as a result of a predominance of young fish in the recovering population.

Reproduction

Adult Dolly Varden in Clevenger Creek were not included in estimates of fish density, biomass or production, since the density of these anadromous fish changed greatly by season; the greatest number was usually seen after their ascent, in October and November. Their role in the streams appeared to be restricted to reproductive efforts, since they rarely fed in freshwaters (Palmisano, 1971).

The total estimated number of adults in Clevenger Creek in the winters of 1967 and 1968 was 207 and 246, respectively (Table 4). The

Table 4. The total numbers of adult spawners ascending Clevenger Creek in the fall of the years 1967 through 1971.

	1967	1968	1969	1970	1971
NUMBERS OF ADULTS:	207	246	32	153	55

major mud spill occurred from mid-May to mid-June 1969, when most of the adults (those of the 246 that survived the spawning effort) had already returned to sea. Their anadromous habit enabled these to escape the mud spill.

Only 32 adults were estimated in the stream in the winter of 1969. The poor condition of the stream at this time apparently deterred much of the brood stock from ascending to spawn. Nevertheless, successful redds were noted. The following winter a total of 153 adults was estimated in the stream, but only 55 were noted in the winter of 1971. The favorable condition of Clevenger Creek, after flushing, apparently permitted use by the brood stock in late 1970. However, in 1971 natural mortality of these fish, in addition to minimal recruitment (since the young fish, or potential brood stock, was decimated in 1969), decreased their numbers greatly.

A hypothetical age structure of the Dolly Varden population in Clevenger Creek illustrates the entire potential effect of the mud spill on this fish population (Table 5). It also reveals the significance of immigration to the repopulation of this species in the polluted area.

The mud spill of 1969 decimated all of the juvenile fish in the receiving waters. Only those juveniles (age group 0 - V) above the

Table 5. The hypothetical age structure of Dolly Varden in the affected area of Clevenger Creek from before the mud spill (1968) to the predicted recovery of the population (1979). Average maximum life expectancy is assumed to occur in the age group IX. The age groups in the area between the dashed lines A and B are dominated by immigrants from outside of the study area. The age groups in the area between the dashed lines C and D are the result of reproduction by a predominance of immigrants.

	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979
	0		0	0	0	0	0	0	0	0	0	0
	I		I	I	I	I	I	I	I	I	I	I
	II		II	II	II	II	II	II	II	II	II	II
	III		III	III	III	III	III	III	III	III	III	III
Spawners	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV	IV
	V	V	V	V	V	V	V	V	V	V	V	V
	VI	VI	VI	VI	VI	VI	VI	VI	VI	VI	VI	VI
	VII	VII	VII	VII	VII	VII	VII	VII	VII	VII	VII	VII
	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII	VIII
	IX	IX	IX	IX	IX	IX	IX	IX	IX	IX	IX	IX

spill point and those adults (age groups IV - IX) feeding at sea survived (Table 5). These adults continued to spawn in the stream and feed at sea until the youngest reached a maximum life expectancy at age group IX in 1973. The diminishing numbers of these adults spawned successfully to initiate new year classes starting in 1970. But, were it not for immigrating fish and the weak age group V in 1974, the low number of fish in age group IX would practically negate the natural reproductive potential of the population for a 1975 year class.

Complete recovery of the Dolly Varden population after 1969 would require 10 years, if immigrants were not considered (Table 5). Even then, recovery could not be complete, since the 1975 class would probably be very small or lacking from the near absence of brood stock the previous year. Therefore, the 1975 year class would have to be the product of a brood stock from outside of the study area.

Considering the role of immigrants in repopulation and the manner in which the population most likely responded, it is apparent that immigrating fish were largely responsible for the repopulation of the polluted area within a period of much less than 10 years expected for recovery by the resident fish alone.

The effect of a depleted adult subpopulation to the recovery of the population may be compounded, considering the reproductive potential of the char population in Clevenger Creek. The first large recruitment of adults in 1975 will be composed of young fish with low fecundity, predominantly the age group IV (Figure 13). The reproductive potential will likely be below normal without the presence of the older and larger adults.

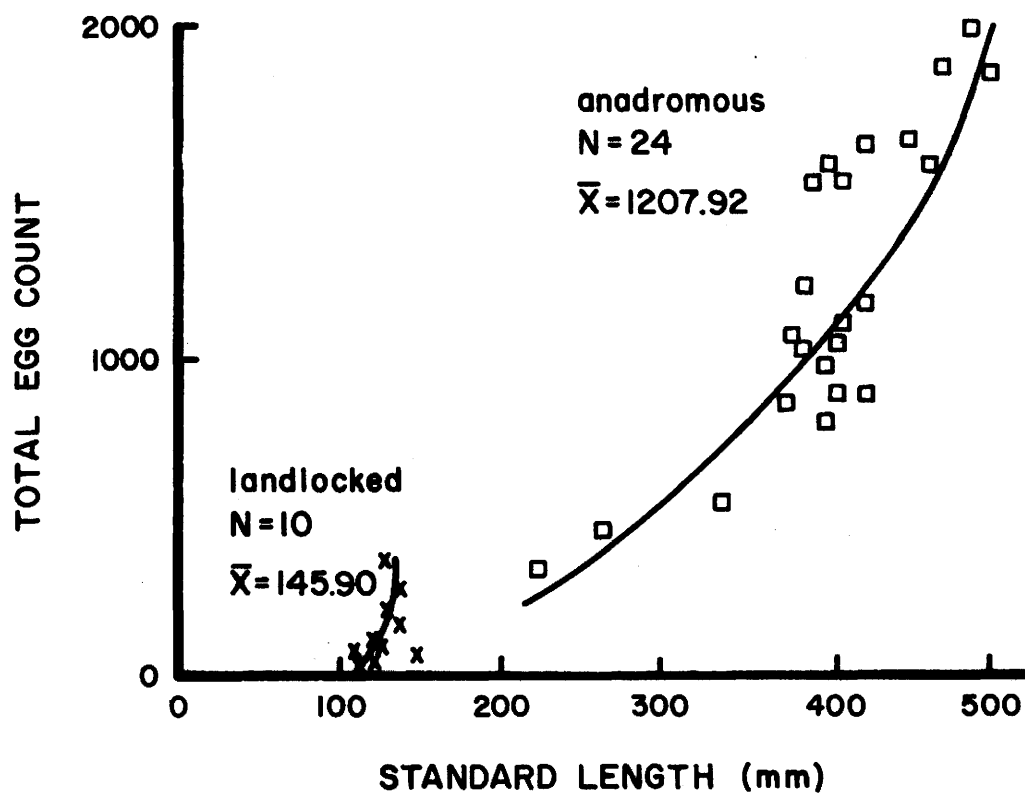


Figure 13. Fecundity of anadromous and landlocked Dolly Varden from Amchitka streams. n = sample size, \bar{x} = population mean. (Regression equation for the anadromous sample is $\log_e y = 3.9952 + 0.0084x$, and that for the landlocked sample is $\log_e y = 1.7631 + 0.0245x$.)

Further ramifications of these fecundity levels for anadromous and landlocked forms will be presented later. For now, the reader should keep in mind the much higher reproductive potential of the anadromous form. Blackett (1973) found a similar disparity in fecundity between the two forms of Dolly Varden in southeastern Alaska; averages of 66 eggs per landlocked female and 1,888 eggs per anadromous female.

Species diversity

Species diversity indices based on the densities of seven species of benthic macroinvertebrates in Clevenger Creek (Figure 14) demonstrate a great deal of variation over the period observed. Nevertheless, there is a general upward trend during recovery from the mud spill of 1969. Diversity indices for macroinvertebrates in an unperturbed Amchitka stream are presented for comparison (Figure 14).

Samples from Clevenger Creek in July 1968 yielded an index of 1.00, with all seven species present. After the spill, the absence or near absence of organisms rendered indices of zero in June, August and September 1969 and 0.69 and 0.58 from the presence of only two species in July and October, respectively. Three species yielded an index of 0.27 in December. These indices demonstrate the sensitivity of this diversity analysis to few species and low levels of abundance.

Indices in 1970 were based on between three and seven species of macroinvertebrates; a maximum index of 0.64 was observed. A distinct upward trend was seen in indices between November 1970 and June 1971. The latter index of 1.01 was the highest of the recovery period observed.

Although species diversity indices between March and December 1971 were based on four, five or six species, a great deal of variation existed in values even 1 month apart. The amplitude of fluctuations

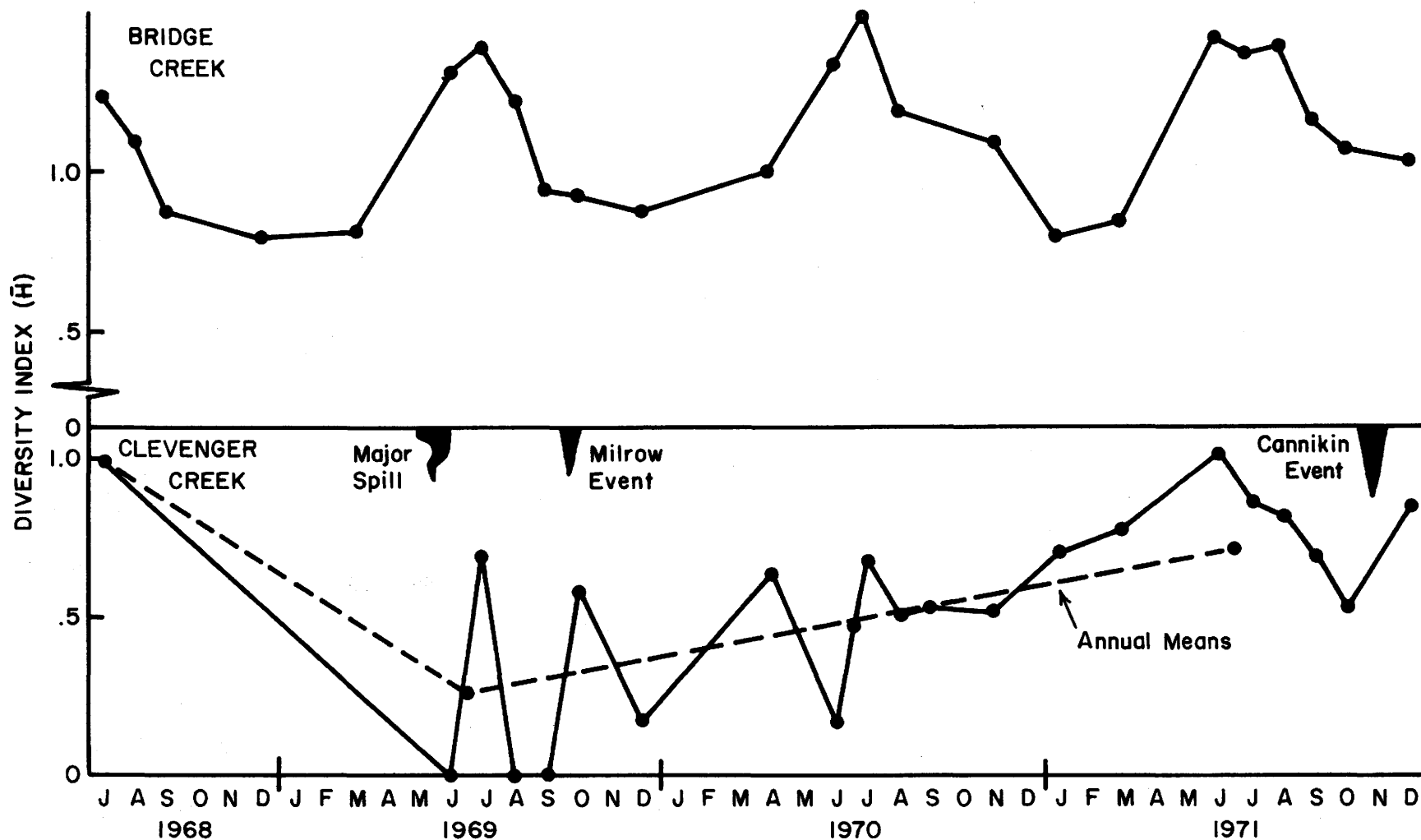


Figure 14. Species diversity (\bar{H}) of macroinvertebrates in Clevenger Creek with respect to the mud spill and the two detonations. Indices of a relatively unperturbed Amchitka stream, Bridge Creek, are presented for comparison.

in indices appeared to be magnified in the presence of so few species. Also, three of the seven species considered in this analysis were univoltine, and the diversity indices tended to respond to seasonal fluctuations in the density of these most abundant species. These fluctuations in species diversity were also observed in the unperturbed stream (Figure 14).

When mean diversity indices of macroinvertebrates in Clevenger Creek were considered, the confounding effect of the large fluctuations was somewhat reduced. Mean indices and the number of monthly observations (n) for 1968, 1969, 1970 and 1971 were 1.00 (n = 1), 0.26 (n = 6), 0.48 (n = 6) and 0.72 (n = 8), respectively. Although a need for additional samples was evident in 1968, the level of diversity before the 1969 spill and the slight upward trend during recovery is better demonstrated by these means than by the monthly indices.

Response of White Alice Creek to Mud Spills

Quantitative data on fishes and macroinvertebrates in White Alice Creek before the July 1968 mud spills from the Cannikin site were not available. Surveys in early 1968 showed that two species of fishes and ten species of macroinvertebrates were present before the first spill (Table 8, see appendix). This was a fauna similar to that of Clevenger Creek, except for the presence of landlocked rather than anadromous Dolly Varden.

Macroinvertebrates

Bottom samples from July 1969 to November 1970 showed that White Alice Creek was devoid of macroinvertebrates from the spill points near

the Cannikin site to near its outlet (Figure 4a). Spills persisted in this area, and there was apparently little or no survival of macroinvertebrates drifting from unaffected areas upstream.

A section extending from the stream outlet upstream about 300 m supported some chironomids, trichopterans, oligochaetes, clams and snails. This area was immediately downstream from several ponds and small rivulets that drained into the stream and apparently diluted the pollutant.

Only midges and oligochaetes were recovered in late 1971, after abatement of the larger and more mud-laden spills (Table 6). Confidence intervals for these point estimates are presented in Table 25. (See appendix.) At least three species of midges were involved in this recolonization; Chironomus riparius, C. plumosus and Chironomus sp. The low numbers of these organisms indicates that drift was chiefly responsible for their presence, although, it is suspected that adults were blown from adjacent unaffected areas the previous summer and deposited some successful egg batches.

The few midges inhabiting the stream in 1971 would have probably provided the brood stock for higher numbers in 1972. However, the Cannikin detonation of November 6, 1971 drastically altered the stream channel and also released additional mud tailings into the stream, when the shock caused two retaining sumps to give way (Figure 4a). The macroinvertebrates were not sampled after the detonation, since much of the stream was drained into large cracks or was impounded by escarpments. Eventually, a large freshwater lake formed in the Cannikin crater, where White Alice Creek once flowed (Figure 4b). Only the last 500 m of White Alice Creek continued to flow and support Dolly Varden and macro-

Table 6. Densities of macroinvertebrates in White Alice Creek, expressed as the mean number of individuals per square meter, before and after mud spills from the Cannikin test site.

TIME AND EVENT	1 ^a	2	3	4	5	6	7	8	9	TOTALS
species encountered in surveys in										
1968:	X	X	X	X	X	X	X	X	X	X
1969										
Jul: Major spills begin										
Jul 1969 to Nov 1970	0	0	0	0	0	0	0	0	0	0
1971										
27 Jan	0	1	0	0	0	0	0	0	0	1
19 Mar	10	14	0	0	11	0	0	0	0	35
8 Jul	16	16	0	0	22	0	0	0	0	54
6 Sep	14	0	0	0	41	0	0	0	0	55
20 Oct	2	0	0	0	15	0	0	0	0	17
6 Nov: Cannikin										

^acode for organisms:

1 = Chironomus riparius
 2 = Chironomus plumosus and Chironomus sp.
 3 = Pseudocloeon sp.
 4 = Limnophilidae
 5 = Oligochaeta

6 = Sphaeridae
 7 = Lymnaeidae
 8 = Leptoceridae
 9 = Simuliidae

invertebrates, while the remainder of the flow did not resume until this detonation crater filled to spill back into the old stream bed, about December 1, 1972 (Gonzalez and Wollitz, 1972).

Samples of lake benthos, after the crater filled in 1973, showed a high density of oligochaetes in the flooded tundra apparently feeding on decaying vegetation of the lake bottom. The few Dolly Varden captured from the lake in August of 1973 and 1974 were gorged with these organisms, as well as larvae of midges, cranflies and beetles (Neuhold, Helm, and Valdez, 1973; Valdez and Helm, 1974).

Fishes

An abundance of landlocked Dolly Varden and a few threespine sticklebacks were found during surveys of White Alice Creek before the 1968 spill. However, these surveys did not include estimates of density. Once the spill decimated the stream populations, no fish were observed until nearly 2 years after the Cannikin event, when Dolly Varden were seen in small ponds formed by escarpments in White Alice Creek.⁶

Two experimental gill nets, set in the water of the filling detonation crater for 24 hours in March 1972, did not yield any fish. Similar sets in August 1973 yielded four Dolly Varden between 125 and 139 mm SL and subsequent sets in August 1974 captured 23 Dolly Varden, from 164 to 256 mm SL. Most of these fish were captured in the lake near its outlet. The fish appeared to be in good condition and were gorged with oligochaetes and larvae of midges, crane flies and beetles.

⁶ Telephone conversation with Mr. Ernest Campbell, Chief of Bio-environmental Branch, Office of Effects Evaluation, U.S. AEC, P.O. Box 14100, Las Vegas, Nevada, September 22, 1972.

An abundance of zooplankton (copepods and rotifers) was also found in Cannikin Lake (Burkett, 1974), but not in fish stomachs.

Two 100-m sections of White Alice Creek, below Cannikin Lake, were electrofished in August 1973 and 1974. The first section was immediately below the lake outlet, where eight Dolly Varden were captured in 1973, and the second section was just below the USGS stream gauge near the stream outlet (Figure 4b), where four Dolly Varden were captured. Similar electrofishing efforts in 1974 yielded 12 and 6 Dolly Varden in the same two sections, respectively. These fish ranged in length from 96 to 261 mm SL and their stomachs were half-filled to full with immature and adult midges. No other species of macroinvertebrates, except for oligochaetes, were found in either the fish stomachs or the stream benthos.

The distribution of Dolly Varden in White Alice Creek and Cannikin Lake indicates that Dolly Varden gained access into the polluted areas via unaffected areas upstream and from tributaries near the stream outlet. However, White Alice Creek did not have the reservoir of fish in ponds and tributaries, as did Clevenger Creek, and recolonization was considerably slower via immigration than in Clevenger Creek. Additional recruitment probably occurred via cracks, which drained three ponds during the detonation. The introduction of Dolly Varden from other nearby waters by well-meaning humans was also a source of recruitment.

Natural reproduction of the fish in Cannikin Lake will depend largely upon the availability of spawning sites. Fecundity is relatively

low in these landlocked forms (Figure 13) and recruitment from reproduction will be much lower than that of the anadromous forms in Clevenger Creek.

An aquatic community appeared to be establishing itself in Cannikin Lake by August 1974. The mud tailings in the system were either expelled or diluted to render the water in the impoundment suitable for life. The physical habitat of White Alice Watershed was so greatly altered from a stream community to a lake system that the biological structure of the original White Alice Creek can not be expected to be reinstated.

DISCUSSION

The macroinvertebrate species diversity of Amchitka streams is considerably lower than that of most continental streams (Wilhm, 1970). According to the diversity-stability hypothesis, these insular communities are expected to be relatively unstable. However, the rapid and nearly complete recovery of fishes and macroinvertebrates in Clevenger Creek 5 years after drilling mud spills, indicated at least moderate stability.

Other studies describing the recovery rate of fish populations are available, but none describe a similar perturbation or similar effects, by which to evaluate relative stability of Amchitka streams (Gunning and Berra, 1969; Bergerson, 1972; Etnier, 1972; Sigler, et al., 1972; Hanson and Waters, 1974; Olmsted and Cloutman, 1974). Thus, the judgement concerning stability in Clevenger Creek was made in spite of a lack of comparative data from more diverse continental streams.

Ideally comparative studies would be the best test of stability; of two natural systems subjected to similar perturbations, the first returning to its pre-spill character would probably be the more stable. Such situations rarely exist, except in experimental design. Even then, stability becomes a qualitative and relative condition, in which an investigator must render a judgement based on his knowledge of several systems.

The methods of evaluating the recovery of perturbed communities are equally dilemmatic. Species diversity indices, production and standing crop were all considered before and after the spills as means for deter-

mining when the community had returned to its natural state. This study shows that species diversity indices may falsely indicate complete recovery of a community; although macroinvertebrate diversity in Clevenger Creek was nearly equal before and 5 years after the spill, three of the nine sympatric species were still below pre-spill densities. The diversity of this simply-structured community apparently reflected the differential densities of the sympatric species.

This study also indicates that species diversity indices in simple communities may vary so extensively with seasonal fluctuations in density (especially those of univoltine species) as to be impractical as indicators of subtle perturbations. Chironomus riparius was so dominant in Clevenger Creek that indices fluctuated directly with its density. The low numbers of species in the community and their low densities appeared to magnify these fluctuations. Harima and Mundy (1974) also found that species diversity indices based on fish biomass varied seasonally with density and condition of the fish.

Estimates of standing crop (numbers and biomass) were also used to evaluate recovery. This was not considered to be a good index, since rate of growth, birth and death was not considered in such estimates.

Hanson and Waters (1974) used rate of production as a sensitivity index to the well-being of a population and to reflect changes in habitat quality. The work on Amchitka lends support to this use of production. Unfortunately, computing production for all species in a community can be tedious and time-consuming. However, production of a few key species in each trophic level is feasible, and a significant difference in this estimate before and after a perturbation will

indicate an aberrance in some component of the community. It is possible to determine which species in the community are recovering differentially by examining those components with energetic relationships to the key species. For example, production of Chironomus riparius in Clevenger Creek after the spill was nearly 150 percent of that before, because of the lack of competition from sympatric species and predation by Dolly Varden. In a similar fashion, production of Dolly Varden was also greater after the spill because of a predominance of the faster growing new year classes, accompanied by high survival in the recovering population.

The easiest way to determine energetic relationships in a community is to document the species and determine the avenues of flow between them. This food web structure reveals problematic species in a recovering community, as well as a great deal of additional information about the functional diversity and stability of the community.

Although two communities may support equal numbers of species of equal abundance and thus yield equal species diversity indices, community stability may differ because of differences in the relationships between the species involved (Boughey, 1973). Thus, it is not only the abundance and evenness of species that determine stability, but the energetic relationships between these as well. The highest degree of stability occurs when each species is directly related to every other species in the community via a direct avenue of energy flow.

The total possible avenues of flow between any two trophic levels can be determined as the product of the number of species in the two levels. The food web structure of the Clevenger Creek community (Figure 15) reveals that of the 82 possible avenues of energy flow between

CARNIVORES 2:

CARNIVORES 1:

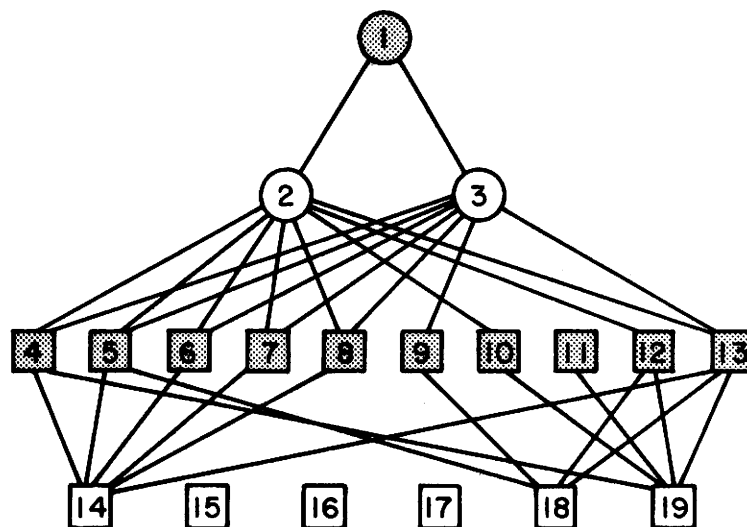
HERBIVORES
&
DETRITIVORESPLANTS
&
DETRITUS

Figure 15. Food web structure of the Clevenger Creek ecosystem, illustrating the species within each of the four principle trophic levels. The avenues of energy flow between species of adjacent trophic levels are represented by straight lines. Thirty-two (39 percent) of the possible 82 avenues existed. The organisms are coded as follows:

- | | |
|-----------------------------------|-------------------------------------|
| 1 = <u>Salvelinus malma</u> | 11 = Limnophilidae |
| 2 = <u>Salvelinus malma</u> | 12 = Sphaeriidae |
| 3 = <u>Gasterosteus aculeatus</u> | 13 = <u>Gnorimosphaeroma lutea</u> |
| 4 = <u>Chironomus riparius</u> | 14 = <u>Fontinalis neomexicanus</u> |
| 5 = <u>Chironomus plumosus</u> | 15 = <u>Mnium</u> sp. |
| 6 = <u>Chironomus</u> sp. | 16 = <u>Carex macrochaeta</u> |
| 7 = <u>Hydrobaenus</u> sp. | 17 = <u>Carex lyngbyei</u> |
| 8 = <u>Pseudocloeon</u> sp. | 18 = <u>Caltha palustris</u> |
| 9 = Simuliidae | 19 = <u>Hippuris vulgaris</u> |
| 10 = Leptoceridae | |

adjacent trophic levels (6 to 10, 10 to 2, 2 to 1), only 32 (39 percent) were documented as actually existing (Neuhold, Helm and Valdez, 1974).

Both low macroinvertebrate diversity and a simple food web structure indicate that, theoretically, the Clevenger Creek ecosystem is highly unstable. Unfortunately, the resistance of the system was not thoroughly tested by the mud spills, since these constituted a toxicity lethal enough to decimate practically any aquatic ecosystem. Nevertheless, the rapid rate and manner in which recolonization occurred indicates a great deal of resilience in the ecosystem; the ability of the population to reinvade former habitat successfully. The stability of these communities may be considered as moderate to high, based on this response.

The physical and highly predictable nature of the stream was a very important feature to this recovery. The short drainages and rapid flushing enhanced expulsion of the pollutant. As long as the habitat was not altered or destroyed, the populations recuperated rapidly. This observation has been made by investigators in other stream situations (Gunning and Berra, 1969; Etnier, 1972; Hanson and Waters, 1974; Olmsted and Cloutman, 1974). The highly physical environment produced a highly predictable situation to which both macroinvertebrates and fishes were observed to be well adapted. The annual series of freshets, for example, also play a vital role in the life cycle of the Dolly Varden; these freshets enable ascent and descent by mature and maturing fish.

This study does not propose to test the diversity-stability hypothesis, but to lend further insight into the relationship between species diversity and community stability by examining a community of low

diversity and its response to unnatural perturbations. Additional studies of this nature are needed to demonstrate responses of both simple and complex communities to unnatural perturbations.

Alternative Methods of Mud Tailing Disposal

No review of pollution effects is complete without recommendations for alleviating problems in future situations involving similar activities. Since the most harmful and long-lasting biological effects to Clevenger and White Alice Creeks, before the detonations, occurred in the presence of chronic mud spills, recommendations to prevent these spills or release them systematically are presented.

A more stable construction of the holding ponds could have prevented or, at least, alleviated the accidental spills. Alternative methods of disposal in similar situations may have to be considered if these wastes cannot be safely held. A system of planned and controlled releases can be devised to minimize biological damage to receiving waters. Toxicity bioassays (96 hour LD₅₀) should be conducted to reveal tolerable levels, and the concentration of the pollutant not allowed to exceed these. As on Amchitka, the concentration of those tailings tested should not exceed about 7 percent, since a solution of 8 percent was lethal to Dolly Varden and 15 percent to threespine stickleback at 8 C water temperature. The tolerance levels to invertebrates and other stream life should also be determined. Thus, the pollutant can be released only periodically to prevent chronic spills and in volumes which the stream can readily flush and eventually neutralize.

Where anadromous fish inhabit the receiving stream, the preferred time to discharge the wastes is when the brood stock is at sea and the young fish in the stream are beyond the sensitive egg and larval stages. It is also desirable to release the wastes during runoff or at high flow levels to accelerate flushing of the pollutant from the system. Although flow in the streams of Amchitka is greatest from August to February, release of wastes at this time could cause damage to egg deposits and death to the already weakened brood stock. On Amchitka, the preferred time for release is mid to late July, when the brood stocks are usually at sea and the young in the stream are past the sensitive egg and larval stages. This allows time for the stream to flush itself before return of adult pink salmon and Dolly Varden in September and October.

Attempts should be made to prevent pollution of an entire stream. The rapidity by which the fishes and macroinvertebrates of Amchitka streams recovered was possible only because a source of recruitment was available. Olmsted and Cloutman (1974) also discussed the importance of leaving a portion of the population undamaged to repopulate areas decimated by pesticides.

An alternative to the release of these muds into streams is to transport the solution offshore via pipelines. As on Amchitka, the coastline was less than 2 km from either test site. However, the disposal area would have to extend beyond the intertidal zone where flushing rate is high, and the area is not extensively used by marine life, such as sea otters, commercial fishes and crustaceans.

These ideas on timing, duration and concentration of waste releases are very specific to streams on Amchitka. Nevertheless, these might apply to similar situations where disposal of tailings is a problem, such as on the North Slope of Alaska (Brooks, et al., 1971), where it has already been demonstrated that proper monitoring of waste disposal, in conjunction with knowledge of the dynamics of the communities, can reduce hazards to aquatic systems.

SUMMARY

Drilling muds from two device emplacement holes, in which the United States Atomic Energy Commission tested two nuclear devices (Milrow and Cannikin) underground, decimated most of the fishes and macroinvertebrates in two streams (Clevenger and White Alice Creek) of Amchitka Island, Alaska. These spills occurred 4 months to 2 years before the detonations, when the dikes of earthen sumps containing the highly basic ($\text{pH} \approx 10$) drilling muds broke and released the fluid into about 70 percent of the total area of these nearby streams.

Rapid flushing rates in both streams, caused by heavy seasonal rainfall, sped the expulsion of these drilling muds. Although the communities of these streams demonstrated no resistance to the pollutant, recolonization began 1 month after abatement. The benthic macroinvertebrates, especially the midge Chironomus riparius, reinvaded both streams via drift from unaffected tributaries and areas above the spill points. This was aided by natural reproduction the following year and by the movement of aerial adults from nearby unaffected waters. A nearly complete recovery of macroinvertebrates was observed in Clevenger Creek 5 years after the spill. The recolonization of this fauna in White Alice Creek was hindered by physical alterations in the watershed, resulting from the Cannikin event. The repopulation of fish was slower and differed between the two streams.

Immigration of juvenile Dolly Varden from unaffected ponds, tributaries and the marine intertidal zone accounted for much of the recolonization by fish in Clevenger Creek. This was enhanced by natural reproduction from anadromous adults feeding at sea during the mud spill.

Redds of these Dolly Varden and some pink salmon were successful 3 to 5 months after spill abatement and 1 month after the nearby Milrow event (October 1969). Adequate supplies of macroinvertebrates were available as food for the young fishes. The Milrow detonation did not interfere with recolonization of Clevenger Creek, in spite of some bank sloughing and increased turbidity caused by the shock wave.

Chronic mud spills in White Alice Creek decimated the wholly landlocked population of Dolly Varden in the receiving waters. Immigration was unsuccessful because the persistence of the spills inhibited complete flushing of the pollutant from the stream. Recruitment by natural reproduction was also slow, since most adults and juveniles in the watershed were killed by the spills. The Cannikin detonation (November 1971) created a large basin in the White Alice Watershed, further inhibiting repopulation of Dolly Varden by destroying their stream habitat.

Growth rates of Dolly Varden and Chironomus riparius did not differ significantly before and after the spills, indicating that the effects were not manifested as physiological maladies on the fish and macroinvertebrates. Low levels of fish production for 2 years after the spills (11.28 and 11.13 kg ha⁻¹, dry weight) were due to low numbers of fish. However, annual production 3 and 4 years after the spill (42.45 and 43.58 kg ha⁻¹) surpassed the pre-spill estimate (40.21 kg ha⁻¹) because of the predominance of new year classes in the recovering population. Annual production of the recovering midges in Clevenger Creek was comparable to that of an adjacent unaffected stream 3 years after the spill.

Macroinvertebrate species diversity of unperturbed Amchitka streams was low when compared to that of continental streams. The resistance of these low diversity communities was not thoroughly tested, since the mud spills seemed toxic enough to have decimated most stream populations. However, resilience or the reoperative process, appeared high as indicated by rapid recolonization of native species after abatement.

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APPENDICES

Appendix A

Physical and Biological Characteristics
of Clevenger and White Alice Creeks
on Amchitka Island, Alaska

Table 7. Channel and flow characteristics of Clevenger and White Alice Creeks.

CHARACTER	CLEVENGER	WHITE ALICE
Watershed area (ha)	360	210
Gradient (m) elevation:distance	1.0:49.2	1.0:38.3
Mean stream width (m)	1.01	1.36
Mean velocity (m sec ⁻¹)	0.20	0.28
Pool:riffle (%)	72:28	68:32
Effluence type	accessible	inaccessible (waterfall)
Predominate substrate	mud	mud

Table 8. Relative abundance of macrophytes, macroinvertebrates, and fishes in Clevenger and White Alice Creeks. ab = abundant, nu = numerous, ra = rare, abs = absent.

MACROPHYTES AND ORGANISMS	STREAMS	
	Clevenger	White Alice
Macrophytes		
<u>Fontinalis neomexicanus</u>	ab	ab
<u>Mnium</u> sp.	ab	ab
<u>Carex machrochaeta</u>	nu	ab
<u>C. lyngbyei</u>	nu	ab
<u>Caltha palustris</u>	ra	ra
<u>Hippuris vulgaris</u>	nu	nu
Macroinvertebrates		
<u>Chironomus riparius</u>	ab	ab
<u>C. plumosus</u>	abs	ra
<u>Chironomus</u> sp.	ra	ra
<u>Hydrobaenus</u> sp.	nu	abs
<u>Pseudocloeon</u> sp.	nu	ra
Simuliidae	ra	ra
Leptoceridae	ra	ra
Limnophilidae	nu	nu
Oligochaeta	ra	nu
Lymnaeidae	abs	ra
Sphaeriidae	ra	ra
<u>Gnorimosphaeroma lutea</u>	ra	abs
Fishes		
<u>Salvelinus malma</u>	ab	ab
<u>Gasterosteus aculeatus</u>	ra	ra
<u>Onchorhynchus gorbuscha</u>	ra	abs
<u>O. kisutch</u>	ra	abs

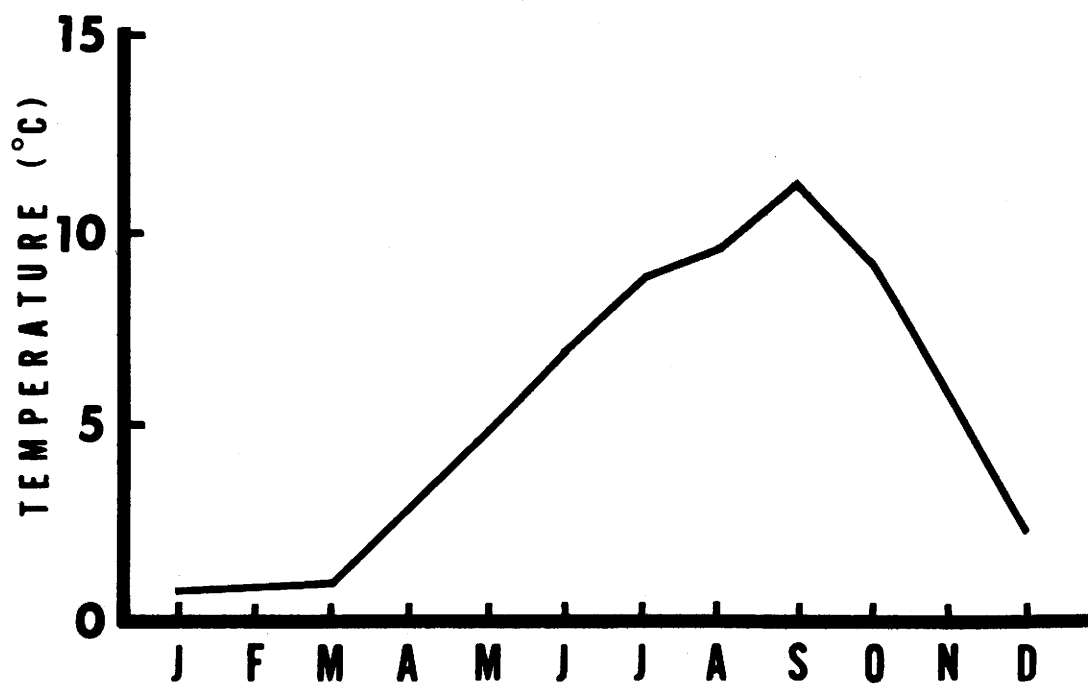


Figure 16. Monthly maximum water temperatures in Clevenger Creek during 1971.

Appendix B

Point Estimates and Confidence Intervals for
Density, Standing Crop and Production of
Chironomus riparius and Dolly Varden
in Clevenger and White Alice Creeks
on Amchitka Island, Alaska

Table 9. Point estimates and 95 percent confidence intervals for densities of Chironomus riparius and juvenile Dolly Varden (age groups 0 - V) in Clevenger Creek before and after the mud spill.

DATE	<u>Chironomus riparius</u> (no.m/2)		Dolly Varden (total stream density)		(no./ha) ESTIMATE
	ESTIMATE	INTERVAL	ESTIMATE	INTERVAL	
1967					
Sep	-		850.60 ± 233.55		4,465.05
1968					
Jan:	First Spill				
May	-		491.46 ± 192.01		2,579.82
Jul	4,686.94 ± 533.14		1,136.50 ± 302.67		5,965.83
1969					
May-Jun:	Major Spill				
29 Jun	0		78.76 ± 3.56		413.43
29 Jul	12.57 ± 4.21		-		-
26 Aug	0		0		0
15 Sep	53.70 ± 10.78		0		0
2 Oct:	Milrow				
3 Oct	44.36 ± 8.91		-		-
18 Dec	3.54 ± 1.98		-		-
1970					
10 Apr	48.33 ± 12.42		-		-
17 Jun	1,119.65 ± 292.36		236.28 ± 54.15		1,240.30
23 Jul	897.54 ± 273.17		304.80 ± 47.34		1,599.99
21 Aug	1,394.56 ± 402.31		344.46 ± 60.78		1,808.17
29 Sep	1,426.01 ± 389.42		-		-
19 Nov	589.89 ± 102.13		-		-
1971					
28 Jan	96.42 ± 27.71		-		-
20 Mar	136.08 ± 36.41		-		-
10 Jun	349.05 ± 48.83		393.80 ± 57.43		2,067.17
31 Jul	4,523.37 ± 899.18		622.20 ± 32.41		3,266.11
19 Aug	5,202.98 ± 1,012.61		732.47 ± 42.28		3,844.95
9 Sep	5,386.11 ± 779.14		874.24 ± 51.16		4,589.15
23 Oct	2,652.78 ± 433.08		-		-
6 Nov:	Cannikin				
12 Dec	892.14 ± 149.98		756.09 ± 145.73		3,968.94
1972					
16 Mar	203.47 ± 50.22		441.06 ± 98.47		2,315.26
27 Jun	-		897.86 ± 122.63		4,713.14
1974					
28 Aug	3,214.00 ± 622.10		1,464.00 ± 201.65		7,684.98

Table 10. Point estimates and 95 percent confidence intervals for standing crops of Chironomus riparius and juvenile Dolly Varden (age groups 0 - V) in Clevenger Creek before and after the mud spill. All values are in grams of dry weight per square meter of stream bed.

DATE	<u>Chironomus riparius</u>		Dolly Varden	
	ESTIMATE	INTERVAL	ESTIMATE	INTERVAL
1968				
Jan: First Spill				
May	-		0.71	± 0.06
Jul	1.97	± 0.43	0.65	± 0.02
1969				
May-Jun: Major Spill				
29 Jun	0		0.10	± 0.01
29 Jul	<0.01	± 0.01	-	
26 Aug	0		0	
15 Sep	0.06	± 0.01	0	
2 Oct: Milrow				
3 Oct	0.08	± 0.02	-	
18 Dec	<0.01	± 0	-	
1970				
10 Apr	0.01	± 0.01	-	
17 Jun	0.31	± 0.07	0.06	± 0.02
23 Jul	0.35	± 0.05	0.20	± 0.04
21 Aug	1.02	± 0.07	0.42	± 0.08
29 Sep	2.08	± 0.12	-	
19 Nov	1.65	± 0.14	-	
1971				
28 Jan	<0.01	± 0.01	-	
20 Mar	0.03	± 0.01	-	
10 Jun	0.10	± 0.02	0.68	± 0.09
31 Jul	1.90	± 0.30	0.43	± 0.07
19 Aug	3.50	± 0.58	0.77	± 0.07
9 Sep	5.73	± 0.81	1.17	± 0.12
23 Oct	7.06	± 0.78	-	
6 Nov: Cannikin				
12 Dec	2.50	± 0.30	0.87	± 0.03
1972				
16 Mar	0.04	± 0.01	0.43	± 0.10
27 Jun	-	±	0.82	± 0.11
1974				
28 Aug	2.43	± 0.48	1.09	± 0.12

Table 11. Monthly instantaneous growth rates of juvenile (age groups 0 - V) and adult (age groups VI - IX) Dolly Varden in Clevenger Creek. \bar{w} = mean individual wet weight in grams. G = monthly instantaneous growth rate.

DATE	AGE GROUPS													
	0	I	II	III	IV	V	VI-IX	G	G	G	G	G	G	G
1 Jan		2.09	9.13	13.33	21.14	30.73	218.68							
1 Feb		0.0558	9.13	13.30	-0.0023	-0.0019	-0.0013							-0.0842
1 Mar	0.09	2.46	9.44	13.73	0.0334	0.0318	0.0267	0.0229						-0.0944
1 Apr	0.13	0.3677	0.1072	0.0333	0.0287	0.0246	0.0217							-0.0557
1 May	0.17	0.2683	0.1078	0.0654	0	0.0245	0.0216							-0.0479
1 Jun	0.25	0.3857	0.2305	0.0321	0.0286	0.0485	0.0424							0.0005
1 Jul	0.44	0.5653	0.1253	0.0630	0.0568	0.0474	0.0418							0.5057
1 Aug	0.75	0.5333	0.2016	0.0917	0.0829	0.0698	0.0614							0.5960
1 Sep	1.10	0.3830	0.2241	0.0298	0.0536	0.0680	0.0604							0.6947
1 Oct	1.54	0.3365	0.1063		0.0790	0.0446	0.0394							0.0266
1 Nov	1.75	0.1278	0.0346	0	0.0766	0.0220	0.0196							-0.0247
1 Dec	1.97	0.1184	0.0334	0.0297	0.0254	-0.0010	-0.0056							-0.1097
MEAN	0.82	5.23	11.23	16.15	25.41	36.08	481.78							
VALUES:	0.3429	0.1340	0.0374	0.0419	0.0341	0.0295	0.1279							

Table 12. Point estimates and 95 percent confidence intervals for production of Chironomus riparius and juvenile Dolly Varden in Clevenger Creek, expressed as grams of dry weight per square meter of stream bed, before and after the mud spill.

DATE	<u>Chironomus riparius</u>			Dolly Varden		
	ESTIMATE	INTERVAL		ESTIMATE	INTERVAL	
1969						
May-Jun: Major Spill						
29 Jun	<0.01	± 0		0.01	± 0	
29 Jul	<0.01	± 0		0		
26 Aug	0.01	± 0				
15 Sep						
2 Oct: Milrow	0.03	± 0.01				
3 Oct	0.02	± 0.01				
18 Dec						
1970						
10 Apr	0.02	± 0.01				
17 Jun	0.11	± 0.03		0.02	± 0.01	
23 Jul	0.42	± 0.08		0.04	± 0.01	
21 Aug	1.07	± 0.22				
29 Sep	1.22	± 0.19				
19 Nov						
1971						
28 Jan	0.02	± 0.01				
20 Mar	0.01	± <0.01				
10 Jun	0.41	± 0.09		0.05	± 0.01	
31 Jul	1.27	± 0.17		0.06	± 0.01	
19 Aug	2.11	± 0.36		0.06	± 0.02	
9 Sep	5.86	± 1.01		0.07	± 0.01	
23 Oct						
6 Nov: Cannikin	2.33	± 0.92				
12 Dec						

Table 13. Computations of production of Chironomus riparius in Clevenger Creek. \hat{N} = estimated density in numbers per square meter, \bar{w} = mean individual wet weight in milligrams, G = instantaneous growth rate, B = dry weight standing crop in grams per square meter, \bar{B} = mean dry weight standing crop in grams per square meter, P = production as grams of dry weight per square meter.

Date	\hat{N}	\bar{w}	G	B	\bar{B}	P
1968						
Jul	4,686.94	1.5		1.97		
1969						
29 Jun	0	1.2		0		
			0.22		<0.01	<0.01
29 Jul	12.57	1.5		<0.01		
			0.55		<0.01	<0.01
26 Aug	0	2.6		0		
			0.43		0.03	0.01
15 Sep	53.70	4.0		0.06		
			0.48		0.07	0.03
3 Oct	44.36	6.5		0.08		
			0.43		0.05	0.02
18 Dec	3.54	10.0		<0.01		$\Sigma = 0.07$
1970						
10 Apr	48.33	0.9		0.01		
			0.10		0.16	0.02
17 Jun	1,119.65	1.0		0.31		
			0.34		0.33	0.11
23 Jul	897.54	1.4		0.35		
			0.62		0.68	0.42
21 Aug	1,394.56	2.6		1.02		
			0.69		1.55	1.07
29 Sep	1,426.01	5.2		2.08		
			0.65		1.86	1.22
19 Nov	589.89	10.0		1.65		$\Sigma = 2.84$
1971						
28 Jan	96.42	0.2		<0.01		
			1.39		0.02	0.02
20 Mar	136.08	0.8		0.03		
			0.22		0.06	0.01
10 Jun	349.05	1.0		0.10		
			0.41		1.00	0.41
31 Jul	4,523.37	1.5		1.90		
			0.47		2.70	1.27
19 Aug	5,202.98	2.4		3.50		
			0.46		4.61	2.11
9 Sep	5,386.11	3.8		5.73		
			0.92		6.39	5.86
23 Oct	2,652.78	9.5		7.06		

Table 13. Continued

Date	\hat{N}	\bar{w}	G	B	\bar{B}	P
1971						
12 Dec	892.14	10.0	0.49	2.50	4.78	$\frac{2.33}{\Sigma = 12.01}$
1972						
16 Mar	203.47	0.7		0.04		
1974						
28 Aug	3,214.00	2.7		2.43		

Table 14. Computations of production of Dolly Varden (1968 year class, age groups 0 through IV) in Clevenger Creek. \hat{N} = estimated density for the study area, \bar{w} = mean individual wet weight in grams, G = instantaneous growth rate, B = standing crop biomass in grams of wet weight, \bar{B} = mean standing crop biomass in grams of wet weight, P = production, expressed as grams of wet weight for the study area (P_1), grams of dry weight for the study area (P_2), and grams of dry weight per hectare (P_3).

DATE	\hat{N}	\bar{w}	G	B	\bar{B}	P_1	P_2	P_3
1968								
May	0	0						
Jul	696	0.28		194.88				
13 Dec ^a	445	2.21	2.0660	983.45	589.17	1,217.20	340.82	1,789.05
			0.7777		585.52	455.36	127.50	669.29
1969								
29 Jun	39	4.81		187.59				
			0.50247		93.80	47.13	13.20	69.27
26 Aug	0	7.95	0.0704	0	0	0	0	0
15 Sep	0	8.53	0.0346	0	0	0	0	0
31 Dec ^a	0	8.83		0				
1970			0.1977		43.04	8.51	2.38	12.51
17 Jun	8	10.76		86.08				
			0.0630		169.10	10.66	2.98	15.67
23 Jul	22	11.46	0.0609	252.12	333.12	20.30	5.68	29.83
21 Aug	34	12.18	0.0605	414.12	478.80	28.98	8.11	42.60
31 Dec ^a	42	12.94		543.48				
1971			0.0593		1,486.85	88.11	24.67	129.51
10 Jun	177	13.73	0.0573	2,430.21	1,614.96	92.57	25.92	136.06
31 Jul	55	14.54	0.0568	799.70	1,238.61	70.37	19.70	103.42
19 Aug	109	15.39	0.0276	1,677.51	2,225.04	61.32	17.17	90.13
9 Sep	203	15.82	0.0281	3,211.46	2,289.07	64.21	17.98	94.37
12 Dec	84	16.27		1,366.68				
1972			0.0544		949.63	51.68	14.47	75.96
16 Mar	31	17.18	0.1054	532.58	848.54	89.45	25.05	131.48
27 Jun	61	19.09		1,164.49				

^aDensity estimated by use of population curves.

Table 15. Computations of production of Dolly Varden (1967 year class, age groups I through V) in Clevenger Creek. N = estimated density for the study area, \bar{w} = mean individual wet weight in grams, G = instantaneous growth rate, B = standing crop biomass in grams of wet weight, \bar{B} = mean standing crop biomass in grams of wet weight, P = production, expressed as grams of wet weight for the study area (P_1), grams of dry weight for the study area (P_2), and grams of dry weight per hectare (P_3).

DATE	\hat{N}	\bar{w}	G	B	\bar{B}	P_1	P_2	P_3
1968								
May	170	4.22		717.40				
			0.0819		715.94	58.61	16.41	86.14
Jul	156	4.58		714.48				
			0.6565		639.80	420.00	117.60	617.32
31 Dec ^a	64	8.83		565.12				
1969			0.2288		426.86	97.66	27.34	143.54
29 Jun	26	11.10		288.60				
			0.1236		144.30	17.83	4.99	26.21
26 Aug	0	12.56		0				
			0.0595	0	0	0	0	0
15 Sep	0	13.33		0				
			0	0	0	0	0	0
31 Dec ^a	0	13.33		0				
1970			0.0296		61.79	1.83	0.51	2.69
17 Jun	9	13.73		123.57				
			0.0287		146.57	4.21	1.18	6.19
23 Jul	12	14.13		169.56				
			0.0854		484.92	41.42	11.60	60.88
21 Aug	52	15.39		800.28				
			0.1100		829.64	91.29	25.56	134.17
31 Dec ^a	50	17.18		859.00				
1971			0.0533		683.18	36.39	10.19	53.49
10 Jun	28	18.12		507.36				
			0.0780		527.94	41.18	11.53	60.53
31 Jul	28	19.59		548.52				
			0.0508		542.19	27.52	7.71	40.45
19 Aug	26	20.61		535.86				
			0.0254		902.13	22.91	6.41	33.67
9 Sep	60	21.14		1,268.40				
			0.0248		796.73	19.73	5.52	28.99
12 Dec	15	21.67		325.05				
1972			0.7558		277.88	210.01	58.80	308.67
16 Mar	5	46.14		230.70				
			0.0747		910.87	68.07	19.06	100.05
27 Jun	32	49.72		1,591.04				
			0.1438		1,541.85	221.73	62.08	325.90
31 Dec ^a	26	57.41		1,492.66				

^aDensity estimated by use of population curves.

Table 16. Computations of production of Dolly Varden (1966 year class, age groups II through V) in Clevenger Creek. \hat{N} = estimated density for the study area, \bar{w} = mean individual wet weight in grams, G = instantaneous growth rate, B = standing crop biomass in grams of wet weight, \bar{B} = mean standing crop biomass in grams of wet weight, P = production, expressed as grams of wet weight for the study area (P_1), grams of dry weight for the study area (P_2), and grams of dry weight per hectare (P_3).

DATE	\hat{N}	\bar{w}	G	B	\bar{B}	P_1	P_2	P_3
1968								
May	222	10.04		2,228.88				
			0.0693		2,271.14	157.30	44.04	231.20
Jul	215	10.76	0.2438	2,313.40	2,529.70	616.61	172.65	906.30
31 Dec ^a	200	13.73		2,746.00				
1969			0.0287		1,464.85	42.07	11.78	61.84
29 Jun	13	14.13		183.69				
			0.0571		91.85	5.24	1.47	7.71
26 Aug	0	14.96	0.0559	0	0	0	0	0
15 Sep	0	15.82	0.0553	0	0	0	0	0
31 Dec ^a	0	16.72		0				
1970			0.1584		58.77	9.31	2.60	13.68
17 Jun	6	19.09	0.0259	117.54	166.52	4.30	1.20	6.33
23 Jul	11	19.59	0.0762	215.49	424.85	32.35	9.06	47.55
21 Aug	30	21.14	0.1463	634.20	635.21	92.92	26.02	136.57
31 Dec ^a	26	24.47		636.22				
1971			0.6531		553.21	361.32	101.17	531.07
10 Jun	10	47.02	0.0926	470.20	441.42	40.86	11.44	60.05
31 Jul	8	51.58	0.0362	412.64	580.68	21.00	5.88	30.87
19 Aug	14	53.48	0.0356	748.72	790.01	28.15	7.88	41.37
9 Sep	15	55.42	0.0177	831.30	584.88	10.36	2.90	15.22
12 Dec	6	56.41		338.46				

^aDensity estimated by use of population curves.

Table 17. Computations of production of Dolly Varden (1965 year class, age groups III through V) in Clevenger Creek. \hat{N} = estimated density for the study area, \bar{w} = mean individual wet weight in grams, G = instantaneous growth rate, B = standing crop biomass in grams of wet weight, \bar{B} = mean standing crop biomass in grams of wet weight, P = production, expressed as grams of wet weight for the study area (P_1), grams of dry weight for the study area (P_2), and grams of dry weight per hectare (P_3).

DATE	\hat{N}	\bar{w}	G	B	\bar{B}	P_1	P_2	P_3
1968								
May	69	13.33		919.77				
			0.0583		827.27	48.21	13.50	70.86
Jul	52	14.13		734.76				
			0.1683		786.66	129.37	36.22	190.15
31 Dec ^a	48	16.72		802.56				
1969			0.0841		401.28	32.27	9.04	47.43
29 Jun	0	18.12		0				
			0.1037		0	0	0	0
26 Aug	0	20.10		0				
			0.0505		0	0	0	0
15 Sep	0	21.14		0				
			0.0494		0	0	0	0
31 Dec ^a	0	22.21		0				
1970			0.7688		0	0	0	0
17 Jun	0	47.91		0				
			0.0371		149.16	5.53	1.55	8.13
23 Jul	6	49.72		298.32				
			0.0907		312.48	28.34	7.94	41.65
21 Aug	6	54.44		326.64				
			0.0878		282.20	24.78	6.94	36.42
31 Dec ^a	4	59.44		237.76				

^aDensity estimated by use of population curves.

Table 18. Computations of production of Dolly Varden (1964 year class, age groups IV through V) in Clevenger Creek. \hat{N} = estimated density for the study area, \bar{w} = mean individual wet weight in grams, G = instantaneous growth rate, B = standing crop biomass in grams of wet weight, \bar{B} = mean standing crop biomass in grams of wet weight, P = production, expressed as grams of wet weight for the study area (P_1), grams of dry weight for the study area (P_2), and grams of dry weight per hectare (P_3).

DATE	\hat{N}	\bar{w}	G	B	\bar{B}	P_1	P_2	P_3
1968								
May	16	18.12		289.92				
			0.0262		265.86	6.95	1.95	10.22
Jul	13	18.60		241.80				
			0.1774		209.74	37.20	10.42	54.68
31 Dec ^a	8	22.21		177.68				
1969			0.7874		88.84	69.95	19.59	102.82
29 Jun	0	48.81		0				
			0.1270		0	0	0	0
26 Aug	0	55.42		0				
			0.0353		0	0	0	0
15 Sep	0	57.41		0				
			0.0348		0	0	0	0
31 Dec ^a	0	59.44		0				

^aDensity estimated by use of population curves.

Table 19. Computations of production of Dolly Varden (1963 year class, age group V) in Clevenger Creek. N = estimated density for the study area, \bar{w} = mean individual wet weight in grams, G = instantaneous growth rate, B = standing crop biomass in grams of wet weight, \bar{B} = mean standing crop biomass in grams of wet weight, P = production, expressed as grams of wet weight for the study area (P_1), grams of dry weight for the study area (P_2), and grams of dry weight per hectare (P_3).

DATE	\hat{N}	\bar{w}	G	B	\bar{B}	P_1	P_2	P_3
1968								
May	14	47.91		670.74				
			0.0186		457.40	8.51	2.38	12.51
Jun	5	48.81		244.05				
			0.1970		181.47	35.76	10.01	52.55
31 Dec ^a	2	59.44		118.88				

^aDensity estimated by use of population curves.

Table 20. Computations of production of Dolly Varden (1969 year class, age groups 0 through V) in Clevenger Creek. \hat{N} = estimated density for the study area, \bar{w} = mean individual wet weight in grams, G = instantaneous growth rate, B = standing crop biomass in grams of wet weight, \bar{B} = mean standing crop biomass in grams of wet weight, P = production, expressed as grams of wet weight for the study area (P_1), grams of dry weight for the study area (P_2), and grams of dry weight per hectare (P_3).

DATE	\hat{N}	\bar{w}	G	B	\bar{B}	P_1	P_2	P_3
1969								
29 Jun	0							
29 Jul	0							
26 Aug	0							
15 Sep	0							
3 Oct	0							
18 Dec	0							
1970								
10 Apr	0							
17 Jun	10	4.81		48.10				
			0.1645		182.81	30.07	8.42	44.20
23 Jul	56	5.67		317.52				
			0.2663		421.46	112.23	31.42	164.96
21 Aug	71	7.40		525.40				
			0.0717		548.90	39.35	11.02	57.84
31 Dec ^a	72	7.95		572.40				
			0.2334		662.70	154.68	43.31	227.35
1971								
10 Jun	75	10.04		753.00				
			0.1004		543.00	54.50	15.26	80.11
31 Jul	30	11.10		333.00				
			0.0629		816.50	51.32	14.37	75.43
19 Aug	110	11.82		1,300.20				
			0.0607		1,453.84	88.28	24.72	129.75
9 Sep	128	12.56		1,607.68				
			0.0298		2,188.42	65.24	18.27	95.89
12 Dec	214	12.94		2,769.16				
			0.0593		2,029.89	120.29	33.68	176.80
1972								
16 Mar	94	13.73		1,290.62				
			0.0573		1,619.49	92.83	25.99	136.44
27 Jun	134	14.54		1,948.36				
			0.0844		1,923.38	162.28	45.44	238.51
31 Dec ^a	120	15.82		1,898.40				
			1.2537		1,226.30	1,537.38	430.47	2,259.64
1974								
28 Aug	10	55.42		554.20				

^aDensity estimated by use of population curves.

Table 21. Computations of production of Dolly Varden (1970 year class, age groups 0 through IV) in Clevenger Creek. \hat{N} = estimated density for the study area, \bar{w} = mean individual wet weight in grams, G = instantaneous growth rate, B = standing crop biomass in grams of wet weight, \bar{B} = mean standing crop biomass in grams of wet weight, P = production, expressed as grams of wet weight for the study area (P_1), grams of dry weight for the study area (P_2), and grams of dry weight per hectare (P_3).

DATE	\hat{N}	\bar{w}	G	B	\bar{B}	P_1	P_2	P_3
1970								
17 Jun	203	0.25		50.75				
			0.9243		87.74	81.09	22.71	119.21
23 Jul	198	0.63		124.74				
			0.4818		139.38	67.16	18.80	98.69
21 Aug	151	1.02		154.02				
			0.7732		220.66	170.61	47.77	250.77
31 Dec ^a	130	2.21		287.30				
			0.7287		381.81	278.23	77.90	408.94
1971								
10 Jun	104	4.58		476.32				
			0.2915		495.62	144.47	40.45	212.33
31 Jul	84	6.13		514.92				
			0.2241		533.58	119.59	33.49	175.80
19 Aug	72	7.67		552.24				
			0.0677		535.68	36.24	10.15	53.28
9 Sep	63	8.24		519.12				
			0.0692		444.99	30.78	8.62	45.25
12 Dec	42	8.83		370.86				
			0.0668		308.15	20.58	5.76	30.24
1972								
16 Mar	26	9.44		245.44				
			0.1620		233.72	37.86	10.60	55.64
27 Jun	20	11.10		222.00				
			0.1831		224.31	41.06	11.50	60.36
31 Dec ^a	17	13.33		226.61				
			0.4107		193.71	79.56	22.28	116.93
1974								
28 Aug	8	20.10		160.80				

^aDensity estimated by use of population curves.

Table 22. Computations of production of Dolly Varden (1971 year class, age groups 0 through I) in Clevenger Creek. \hat{N} = estimated density for the study area, \bar{w} = mean individual wet weight in grams, G = instantaneous growth rate, B = standing crop biomass in grams of wet weight, \bar{B} = mean standing crop biomass in grams of wet weight, P = production, expressed as grams of wet weight for the study area (P_1), grams of dry weight for the study area (P_2), and grams of dry weight per hectare (P_3).

DATE	\hat{N}	\bar{w}	G	B	\bar{B}	P_1	P_2	P_3
1971								
28 Jan								
20 Mar								
10 Jun	0	0.40		0				
			2.0250		168.89	342.00	95.76	502.68
31 Jul	417	0.81		337.77				
			0.2305		373.40	86.08	24.10	126.52
19 Aug	401	1.02		409.02				
			0.2877		479.91	138.06	38.66	202.92
9 Sep	405	1.36		550.80				
23 Oct	-		0.4855		644.47	312.90	87.61	459.90
12 Dec	334	2.21		738.14				
			0.4160		689.00	286.60	80.25	421.25
1972								
16 Mar	191	3.35		639.85				
			0.4455		604.96	269.48	75.45	396.08
27 Jun	109	5.23		570.07				
			0.5572		718.71	400.43	112.12	588.55
31 Dec ^a	95	9.13		867.35				
			0.4653		848.07	394.64	110.50	580.04
1974								
28 Aug	57	14.54		828.78				

^aDensity estimated by use of population curves.

Table 23. Computations of production of Dolly Varden (1972 year class, age group 0) in Clevenger Creek. \hat{N} = estimated density for the study area, \bar{w} = mean individual wet weight in grams, G = instantaneous growth rate, B = standing crop biomass in grams of wet weight, \bar{B} = mean standing crop biomass in grams of wet weight, P = production, expressed as grams of wet weight for the study area (P_1), grams of dry weight for the study area (P_2), grams of dry weight per hectare (P_3).

DATE	\hat{N}	\bar{w}	G	B	\bar{B}	P_1	P_2	P_3
1972								
16 May	0							
27 Jun	371	0.28		103.88				
			2.1188		421.25	892.55	249.91	1,311.87
31 Dec ^a	317	2.33		738.61				

^aDensity estimated by use of population curves.

Table 24. Production of Dolly Varden in Clevenger Creek, expressed as kilograms of dry weight per hectare.

	1968	1969	1970	1971	1972
Age groups					
0	17.89	0	2.51	12.92	13.12
I	7.03	7.39	2.67	8.96	14.06
II	11.38	1.70	1.01	6.09	1.46
III	2.61	0.70	2.04	5.53	5.52
IV	0.65	0.47	2.04	2.17	2.07
V	0.65	1.03	0.86	6.79	7.34
Total Annual Production:	40.21	11.28	11.13	42.45	43.58
Mean Production:	6.70	1.88	1.85	6.24	7.26

Table 25. Point estimates and 95 percent confidence intervals for densities of macroinvertebrates from White Alice Creek after mud spills. Estimates are in numbers per square-meter of stream bottom.

DATE	<u>Chironomus riparius</u>		<u>Chironomus plumosus</u>		<u>Chironomus sp.</u>		Oligochaeta	
	ESTIMATE	INTERVAL	ESTIMATE	INTERVAL	ESTIMATE	INTERVAL	ESTIMATE	INTERVAL
1971								
27 Jan	0		1.02 ± 0.67		0		0	
19 Mar	10.40 ± 1.43		12.45 ± 1.12		2.00 ± 0.40		11.16 ± 1.52	
8 Jul	16.23 ± 1.89		14.01 ± 1.30		1.50 ± 0.36		22.10 ± 2.31	
6 Sep	14.43 ± 1.21		0		0		41.15 ± 5.67	
20 Oct	1.62 ± 0.80		0		0		15.06 ± 1.88	

VITA

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